ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

MAINTENANCE COST REDUCTION STRATEGIES AND MODEL DEVELOPMENT FOR ETHIOPIAN LEATHER INDUSTRY

(A case study in the Ethiopian Tannery Share Company)

By: Zenun Dawd

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled “Maintenance Cost Reduction Strategies and Model Development for Ethiopian Leather Industry: case in Ethiopia Tannery Share Company” is original work of my own, has not been presented for a degree of any other university and all the resources of materials used for the thesis have been duly acknowledged.

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ABSTRACT

Maintenance is the combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to a state in which it can perform the required function. One way that companies can regain control over their costs is not only to assess these costs, but also systematically classify and identify the various costs that are associated with maintenance. Therefore, a maintenance cost reduction strategy is important to reduce maintenance cost. In this study, the factors increasing maintenance cost, identification of critical machines, causes of machines breakdown, and availability of purchasing, finance and maintenance strategy were assessed.

A set of four year maintenance cost data were collected for the identification of factors increasing the maintenance cost. To analyze the data six sigma tools, which are pie charts, Pareto charts, fishbone diagram, histogram and ABC equipment classification methods were used. Due to shortage of recorded data on breakdown time impossible to find maintenance cost associated with breakdown.

Based on the analysis main factors increasing maintenance cost were identified. The data analysis showed that the spare parts and outsourcing maintenance work cost account 66% of the maintenance cost. So that the spare part and outsourcing maintenance work take to further investigation.

On the other hand the result from the analysis shows that the company has no proper maintenance strategies to different machines, record keeping and documentation on maintenance activities and history and they have knowledge and skill gap on how to maintain a machine, how to use maintenance tools and over all, unavailability of all-inclusive and standardized maintenance, purchasing and financial strategy that reduce maintenance cost to follows.

This paper proposed lean maintenance strategy and develop a model through incorporating the lean maintenance strategy for the reduction maintenance cost, considering the existing problem. The model simplifies the whole process and makes the activities to be efficient and standardized.

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LIST OF ABRIVIATION

ABC - Always Better Control

CM - Corrective Maintenance

CMMS - Computer maintenance management system

Dep - Department

DMAIC - Define, Measure, Analyze, Improve and Control

e.g - example

ETSC - Ethiopia Tannery Share Company

FMEA - Failure mode and effect analysis

JIT - Just in time

LSS - Lean six sigma

M - Maintenance

MI - Maintenance Improvement

MRO - Maintenance, Repair and Operation

OEE - Overall equipment efficiency

O.M.W - Outsourcing maintenance work

PdM - Predictive maintenance

PM - Preventive Maintenance

P.S.P - Purchasing spare parts

RCM - Reliability centered maintenance

RCFA - Root cause failure analysis

R & D - Research and Development

SIPOC - Supplier, Input, Output and Customer

SOP - Standard Operation Procedure

VCM - Visual management system

VOC - Voice of customer

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study

The leather industry is one of the many economic sectors, which should be given attention for the development of Ethiopia. This sector is one of the leading industries playing a significant role in the generation of foreign currency and contribution in employments opportunity which ultimately the country utilizes, for developing all the other sector of its economy (Misikr, 2006).

Maintenance is all the function to replace or repair to a machine, equipment, or production line in order to restore or prevent the production processes. Maintenance considered from the fastest growing disciplines in the industry region and this is happen with the production expanding and its sophistication equipment, maximize the return of the investment, minimize the maintenance cost, and simplify the complexity of the maintenance functions (Abbas Al-Bawi). An effective and efficient maintenance procedure would operate the maintenance system to achieve improvement in operational objectives successfully (Meseret, 2007). These improvements generally involve better utilization of resources and resulted in higher level of quality.

Often, managers make operational and tactical decisions that are short term in nature, for example purchasing decisions may be based only on breakdown events and preventive maintenance may be ignored. This strategy will help reduce expenses in the short term but impacts may be experienced later in the form of increased breakdowns and unavailability (Meseret, 2007).

Maintenance is a part of the production and manufacturing from the beginning, without maintenance machines, tools, equipment, and buildings will stop after period of time, maintenance ensure everything work correctly until the end of cycle life.

In recent years, industry managers have been gradually moving to the idea that maintenance can be a profit generating function rather than merely a cost center (Eyerusalem Mekasha, 2018). When it comes to issues such as reliability, availability, safety, quality, and cost-effectiveness levels of plant and equipment there is no doubt that the cost of maintenance can be high and often representing a significant portion of recurrent budgets (Kym Fraser et al, 2015). (Eyerusalem Mekasha, 2018). One way that companies can regain control over their costs is not only to assess these costs, but also systematically classify and identify the various costs that are

associated with maintenance (Imad, 2004). Using a systematic approach to perform cost reduction not only yields cost improvement but provides decision-makers with the trade-offs involved in achieving these reductions (Imad, 2004). Maintenance cost usually consists of direct and indirect costs. Direct (visible) costs comprise factors such as direct labor, e.g. manpower, direct material, e.g. spare parts, and overheads, e.g. tools, transportation, training and methods. Indirect (invisible) costs are all the costs that may arise due to planned and unplanned maintenance actions, e.g., lost production costs, accidents, etc (Michal, 2017).

In order to fit the needs, reduce the cost, and eliminate downtime companies started to improve their maintenance strategy through the use of maintenance management strategy.

The management strategy planned to use in this thesis is six-sigma and lean maintenances. Lean Six Sigma as a methodology that focuses on the elimination of waste and variation, following the DMAIC structure, to achieve customer satisfaction with regards to quality, delivery and cost (ThiBao, 2017).

Companies practicing either Lean or Six Sigma alone might reach a point of diminishing costs and the benefits of deploying Lean Six Sigma as a unified methodology have been proved in many companies from giants to smalls across industries. The most recognizable benefit is increase in profit and financial savings. A case study done in a small engineering company in UK reports that the integrated implementation of Lean Six Sigma on the production line where the pilot was implemented, there was a 55% reduction in scrap costs, an increase in overall equipment effectiveness (OEE) from 34 to 55%, a 34% increase in the time available for production and a 12 percent reduction in energy consumption per year (ThiBao, 2017).

To ensure the plant operates at the required condition while meeting its production targets at an optimal cost, maintenance management has to make conscious decisions regarding the maintenance objectives and strategies that need to be pursued.

To select the appropriate maintenance strategies and develop a model in this paper use both lean and six sigma. Six sigma used to define, measure, analyze, improve and control the existing maintenance process, and strategies of Ethiopia tannery Share Company. Based on the result of DMAIC and using lean principles select maintenance strategies and develop a model that reduces maintenance cost of the company.

1.2. Statement of the Problem

These days, survival of any company is strictly on its competitiveness in the market. The competition may be in a national or international level.

Most organizations in Ethiopia lack efficient maintenance and spare part management system that affects the total output (Misikr, 2006). In Ethiopian Tannery Share Company the corrective maintenance highly dominates and it cover more than 85% of the total maintenance activity from the researcher observation, the output of the analysis and according to the maintenance manager of the company (Zeleke Leilor personal communication December 20 2018 in Modjo Ejersa).

There are various factors that increase the maintenance cost of the company machine failure is usual and repeated. Most of the works are outsourced, and there is no standard system to select external workshop. Spare part requirements are very high, during purchasing process there is no standard procedure this increase transportation and spare part cost.

Maintenance has received little notice in most organization, which makes the availability of the machines to decrease. This directly affects the productivity and increase the maintenance cost of the organization (Misikr, 2006). Most organizations in Ethiopia lack efficient maintenance management system that affects the total output (Misikir, 2004) (Meseret, 2007) (Mahilet Mentesinot, 2017). Leather industries are one among these that lack efficiency in maintenance. Through observation, interview and questionnaires with maintenances, purchasing and finance department managers and personnel's identified that Ethiopian Tannery Share Company faces problems on maintenance management system. The major problems identified are:

- Unable to identify the major factors that increase maintenance cost
- Skill gaps to identify the causes of machine breakdown
- Unable to Select appropriate maintenance strategies to critical and frequently failure machines
- Unable to providing training to machine operator regarding failure causes
- Lack standard procedure in the purchasing of MRO item or spare parts and machineries and outsourcing of maintenance works.

1.3. Research Questions

The problem discussion leads to the following research questions:

- What are the major factors increasing the maintenance cost and the underlying causes?

- How to select appropriate maintenance strategies to the critical & frequently failure machine?
- How to manage maintenance spare part requirement and build cost effective SOP in purchasing and outsourcing of maintenance works?

1.4. Objective

Through consideration of the above problems, this thesis planned to achieve the following objectives.

1.4.1. General Objectives

The main objective of this study is to propose maintenance cost reduction strategies and develop a model through integration of Six Sigma and lean for Ethiopia Tannery Share Company.

1.4.2. Specific Objective

- To analyze major factors increasing maintenance cost and the underlying causes using six sigma tools in ETSC.
- Select the appropriate maintenance strategies to critical and frequently failure machines
- To suggest standard operation procedure (SOP) in the purchasing, replacement of spare parts and outsourcing of maintenance works in ETSC

1.5. Significance of the Study

The significance of this research is to explore a solution to the identified problem related to maintenance. It should minimize the maintenance cost; assess the main cost incurred area, the existing maintenance operation, using six sigma tools which is DMAIC methodology.

Based on the results of the analysis for the various factors that increase the maintenance cost of the company select appropriate maintenance strategies and develop a model that helps to reduce the maintenance cost of the company.

In general this research is beneficial if it is implemented by the case company and other similar manufacturing industries for the improvement of maintenance method, minimizing cost and increase profits.

1.6. Scope of the Study

The study was conducted in ETSC which is located in Modjo Ejersa. The study focuses on the analysis of the existing maintenance, purchasing and finance strategy of the company to decrease the maintenances cost. And this is limited to the area of maintenance cost reduction through assessing the main cost incurred area, existing maintenance operation, strategy and method of the company.

1.7. Organization of the Study

The study has five chapters. The first chapter is about introduction of the study. It contains background of the study, statement of the problem, research questions, and objective of the study, significance of the study and scope of the study.

The second chapter is intensive related literature review on maintenance, maintenance cost, maintenance strategy, maintenance management method such as six sigma and leans, DMAIC tools, lean tools and techniques and spare part request and purchasing procedure of the case company.

The third chapter is research methodology. In this chapter Data collection method and methodology framework are presented in detail. The fourth chapter data collection, analysis & discussion for the case company and in this chapter the detail analysis of the study, proposed lean maintenance strategy and develop a model that helps to reduce maintenance cost of the case company. Finally, conclusions and recommendations are forwarded.

CHAPTER TWO

2. RELATED LITERATURE REVIEW

2.1. Conceptualization of Cost and its Element

According to CCA (the association for low cost operations), the definition of cost is the resource expense for having added value to the process and the result (XuZhiran, 2012). Carroll considered that cost reduction can help companies keep competitive positions. In typical manufacturing companies, maintenance costs are between 15 and 40 percent of the total cost of production (Wireman, 2014).

According to Jinkens and Yallapragada cost categories are several kinds of expenses that should be taken into account when a firm is manufacturing a product or providing services. Cost categories can be divided by different situations, for example, fixed costs and variable costs. Maintenance cost attributes are classified into two major categories: direct and indirect cost. The former is associated with costs of periodic inspection and preventive maintenance (PM), repair, overhaul, and servicing as well as the labor and material expenses needed to implement maintenance actions. The latter, indirect cost, is related to: loss of production due to primary equipment breakdown and unavailability of standby equipment; lost opportunities in uptime, yield, and quality due to non-operating or unsatisfactorily operating equipment; deterioration in the equipment life due to unsatisfactory/inferior maintenance, which raises costs to the safety of people, property, and the environment; and operating and maintaining stand by equipment (Fazel and Madjid, 2016).

Compton and Brinker mentioned that every cost is different, and only some should be evaluated for decision-making purposes (Martin 1992). According to the above theory, this research will give the cost structure, linking the cases chosen.

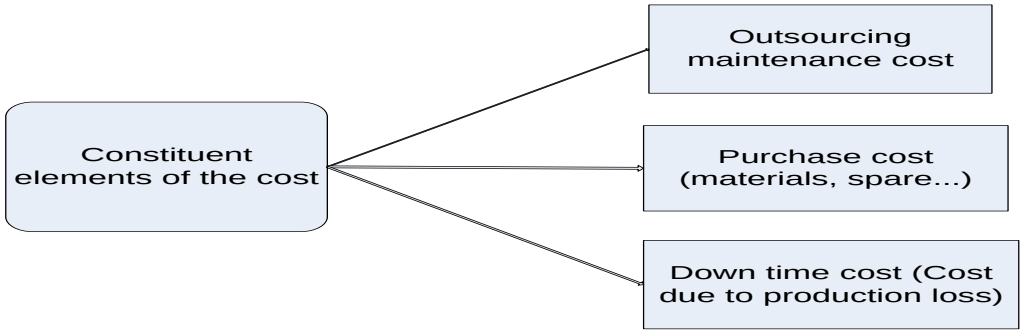


Fig 2.1: Constituent elements of the cost (developed by the researcher)

2.2. Factors Impact on Cost Reduction

Initially, the difference between cost reduction and cost control should be given attention. Cost reduction is an unstoppable process of critical cost examination, analysis and challenge of standards (XuZhiran, 2012). Mersereau pointed out that cost reduction exists everywhere in the business, in other words, productions, processes, manufacture, methods, organization and staff should be considered. Moreover, cost reduction is critically examined and reviewed with a view to improving efficiency and effectiveness and reducing the costs (Martin 1992).

Cost reduction is the application of procedures to monitor expenditures and performance against progress of a project and manufacturing operations with projected completion to measure variances from authorized budgets and allow effective action to be taken to achieve minimal costs (Martin 1992).

A lot of literatures have been written about the methods of cost reduction. Cost reduction can be achieved through several approaches. However, there are some popular approaches, like elimination in the form of non-essential, non-value adding activities and modification of manufacturing activity. In short, through in depth analysis, the best and least cost path is adopted for each activity.

McCormick provided 10 steps to reach cost reduction as follows: 1. Set a minimum cost reduction target, 2. Establish whether budgeting can achieve the target, 3. Place cost reduction into the wider strategy of the business, 4. Identify the economic drivers of cost, 5. Analyzing costs with the value chain, 6. Select appropriate tools from the operational tool box. 7. Consider outsourcing non-core activities, 8. Restructure the labor force, 9. Manage the change process carefully, 10. Monitor the results diligently (XuZhiran, 2012).

2.3. Maintenance Cost

Maintenance is all the function to replace or repair to a machine, equipment, or production line in order to restore or prevent the production processes. Maintenance considered from the fastest growing disciplines in the industry region and this is happen with the production expanding and its sophistication equipment, maximize the return of the investment, minimize the maintenance cost, and simplify the complexity of the maintenance functions (Bamber, 2003).

Maintenance cost or maintenance related costs in general divided into direct and indirect cost without putting maintenance savings and profit into consideration (Al- Najjar & Alsyouf, 2004),

(Mahilet Mentesinot, (2017). Direct maintenance costs as costs associated directly to the maintenance activities, which include the internal costs that are required to carry out the maintenance functions e.g. labor, tools, spare parts, training etc. and other maintenance expenses that are directly related (Obamwoni, 2010).

Indirect costs on the other hand includes all costs that are indirectly associated with maintenance, which can be attributed to issues like profit loss due to production losses during planned and unplanned stoppages, customer losses, reputation and consequently loss of market share as a result of maintenance related factors (Obamwoni, 2010).

In addition, indirect maintenance costs includes performance inefficiency costs due to short stoppages and reduced speed, poor quality cost due to maintenance deficiency, idle fixed cost resources e.g. idle machine and idle worker costs during breakdowns, delivery delays penalty cost as a result of unplanned downtime, assurance claim from dissatisfied customers as a result of maintenance related poor quality (Mahilet Mentesinot, (2017).

Downtime failure always results in a reduction of overall plant efficiency and an increase in maintenance and operating cost. That is why new maintenance strategies, policies, and related techniques are the areas of research interest of many researchers. For the purpose of describing maintenance operations, it is convenient to think of equipment as a collection of interrelated parts. Maintenance operations consist largely (but not solely) in replacing parts of equipment (Arts, 2013).

2.4. Maintenance Strategies

Maintenance strategies determine when parts or equipment need to be replaced or maintained. Throughout this subsection, we focus on the decision to maintain/replace a part, but the discussion also applies to the decision to maintain/replace equipment.

Modificative maintenance concerns interchanging a part with a technically more advanced part in order to make the equipment perform better (Arts, 2013). The maintenance strategies that occur most often are preventive and breakdown corrective maintenance. Under a breakdown corrective maintenance strategy, a part is not replaced until it has failed, while under a preventive maintenance strategy, the aim is to replace parts before failure occurs. (Off course, this aim may not always be achieved: A part can breakdown before its replacement occurs.) Breakdown

corrective maintenance is an attractive option for parts that do not wear, such as electronics. For parts that do wear, it can be beneficial to follow a preventive maintenance strategy (Arts, 2013).

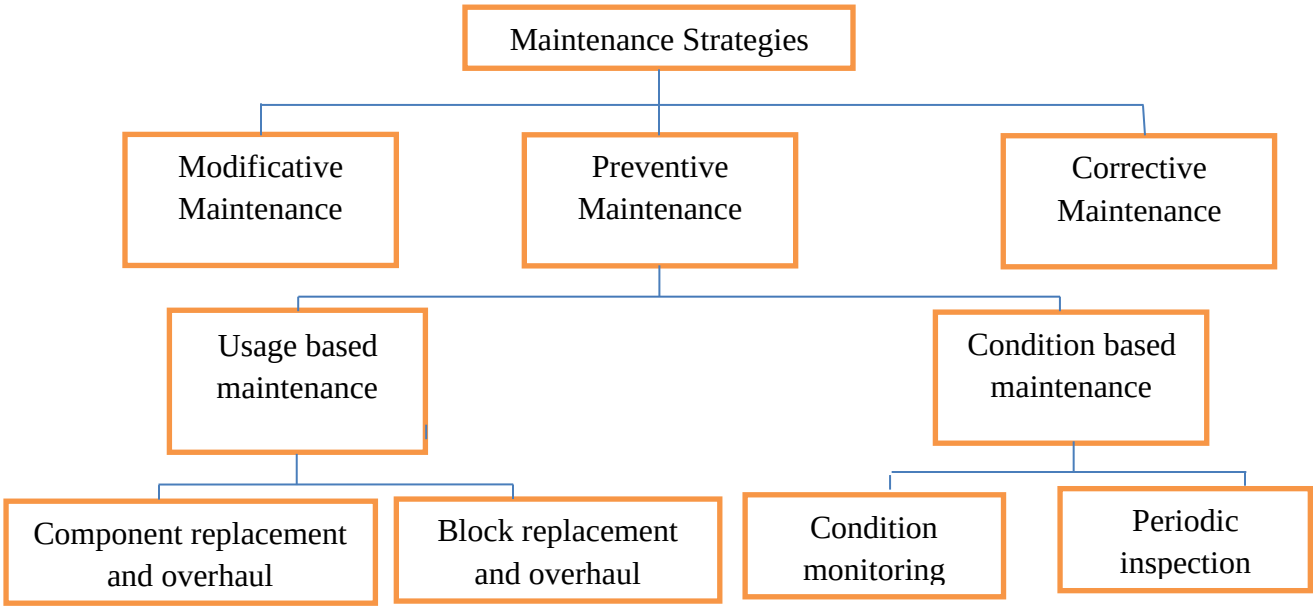


Fig 2.2: Maintenance strategies (Arts, 2013).

Preventive maintenance strategies can be further divided into usage and condition based maintenance. Under usage based maintenance, the total usage of a part is measured and maintenance is conducted when a certain threshold level has been reached. The usage of parts can be measured in many ways depending on the nature of the equipment. Time in the field is perhaps the most common mean to measure usage.

In condition based maintenance, the actual condition of a part is gauged and maintenance is conducted based on this. The condition of a part can be measured either periodically during inspections (Periodic inspections) or continuously through a sensor (Condition monitoring). How the condition of equipment is measured depends on the nature of equipment (Arts, 2013).

The characteristics of a company that need to implement preventive maintenance (Eyerusalem, 2018):

- Low equipment uses due to failures
- Large volume of scrap and rejects due to unreliable equipment
- Rise in equipment repair costs due to negligence in areas such as regular lubrication, inspection, and replacement of worn items/components
- High idle operator times due to equipment failures

- Reduction in capital equipment expected productive life due to unsatisfactory maintenance

Some of the main objectives of PM are to:

- Enhance capital equipment productive life,
- Reduce critical equipment breakdowns,
- Allow better planning and scheduling of needed maintenance work,
- Minimize production losses due to equipment failures, and promote health and safety of maintenance personnel.

On preventive maintenance strategy equipment's needs to be inspected periodically, lubricate, cleaned, calibrated, tested all electrical & mechanical parts are fully functional and replaced any damaged parts so as to run the equipment in a good condition (Eyerusalem, 2018)

2.4.2. Criticality Classification

Resources are limited and it is therefore necessary to determine how to distribute them. This is to ensure that no important equipment is neglected and that more resources are concentrated on the items which are the most critical. It is therefore necessary to classify equipment according to its importance (Gustav, 2012). Availability of spare parts is a major factor that leads to a reduction of downtime duration when a breakdown occurs. Stocking is on the other hand limited by cost and space. Therefore, by designing the availability of spare parts in an optimal way is of significant importance.

2.4.3. Ways of Identifying Critical Equipment

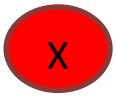
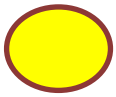
According to Börjesson and Svensson determination of the equipment criticality should be based on the cost of past events. This type of foundation for prioritization guarantees that maintenance resources are continuously focused on equipment which causing the most harm to the organization. A more robust production will be obtained by continuously improving the most critical equipment. The classification model constitutes of three blocks; knowledge foundation – Competence, knowledge and data, cost model for failures – prioritize with regard to cost which is a uniform measure, and stratification and prioritization – help to prioritize, stratifying costs to find the most critical equipment. To support the classification method are work methods such as data collection, operator maintenance, proper performance measures and improvement projects.

Another method to use for classification of equipment is the Always Better Control (ABC) classification of equipment is used in order to assess the need of maintenance and to optimize the maintenance activities (Gustav, 2012).

The classification is made with regard to six factors:

1. Safety risk associated with breakdowns – **S**
2. Quality problems, customer complaints or scrap – **Q**
3. The extent of time during which the equipment are used for production – **T**
4. Obstacles that arise in the production process, which affect the lead time, due to the equipment breakdown - **O**
5. Failure frequency – **F and**
6. Mean Time To Repair (MTTR) - **M**

Table 2.1: Rules for the classification of equipment (Ylipaa, 2007, Gustav, 2012)

			
S	High Risk	Low Risk	Insignificant Risk
Q	High Risk	Low Risk	Insignificant Risk
T	24hrs/day	8-24hrs/day	8hrs/day
O	Cause a stop in the whole process	Don't stop the process but cause losses	Don't stop the process
F	F>1 failure /2months	1 failure /2 months – 1 failure /6 months	F< 1failure /6months
M	MTTR > 2hrs	0.5 < MTTR <2hrs	MTTR < 0.5 hrs

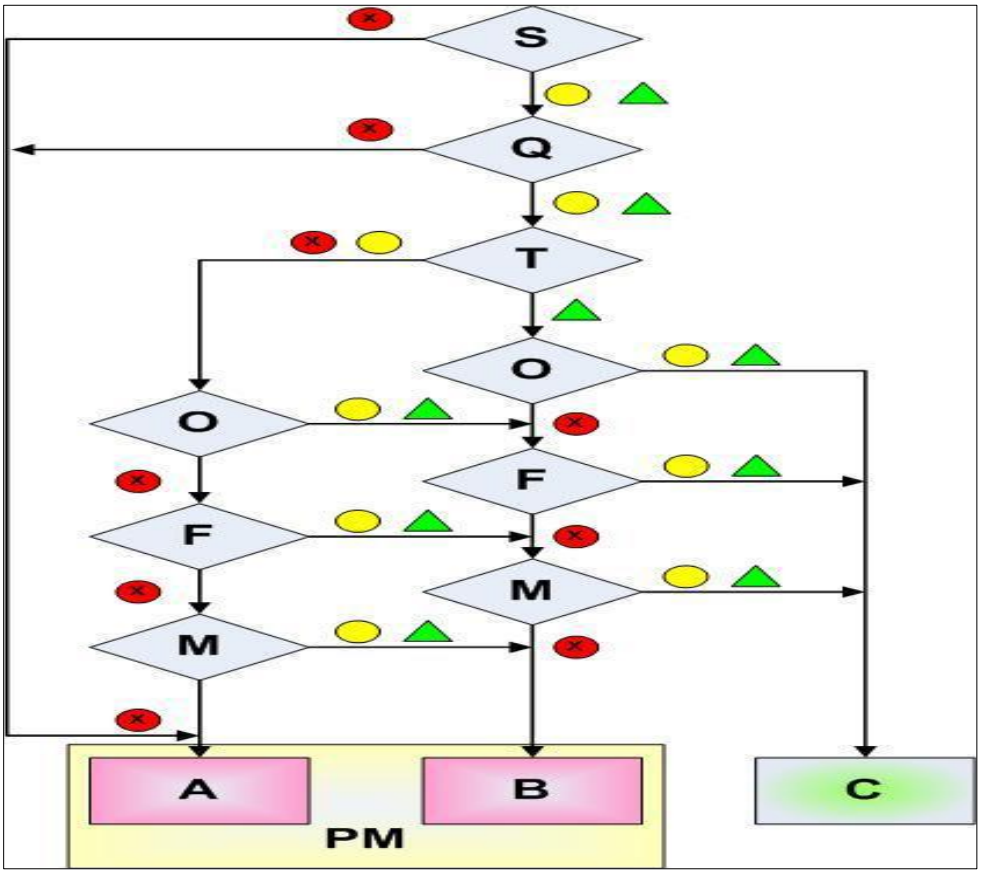


Figure 2.3: A flow chart which represents the process of classifying equipment (Ylipaa, 2007, Gustav, 2012)

As can be obtained in table 2.4 and Figure 2.5 above the process consist of answering the following questions for the equipment:

1. How high is the safety risk?
2. How high is the quality risk?
3. How many hours per day is the equipment used for production?
4. How is the production process affected by the equipment breakdown?
5. What is the failure frequency?
6. What is the mean time to repair?

According to Figure 2.3 a preventive maintenance program developed for equipment classified as ‘A’ or ‘B’. For equipment classified as ‘C’ is no effort made to prevent failures, those failures are allowed to occur and then repaired, i.e. a corrective maintenance program.

2.5. Maintenance Management Strategy

The management strategy planned to review in this thesis is six-sigma, and lean maintenance. Many articles, publications and quite a number of books have been written to explain or promote specific strategies to the industry. Competitive marketing of the methods often cause confusion and a procedure to compare and select the appropriate strategies is necessary (Mulugeta, 2009).

2.5.1. Six Sigma Philosophy

The primary goal of Six Sigma is to improve customer satisfaction (and, thereby, profitability) by reducing and eliminating defects. In this case, the defects may be related to any aspect of customer satisfaction: product quality, delivery performance, and product cost Dr. Uday Apte and Dr. Keebom Kang, (2006).

Six sigma reduces waste, increases customer satisfaction and improves process performance while being focused on measurable financial results of the proposed solution.

In this project Six Sigma were used because the principles and tools of the philosophy are well suited for problem analysis. The statistical concepts used in a typical Six Sigma improvement initiative are valuable in addressing the problem at hand from a process engineering and economic perspective (Majeed, 2015).

At the foundation of Six Sigma is the DMAIC cycle (Define-Measure-Analyze-Improve-Control), which will be utilized for structuring the project as well as making use of the statistical and analytical tools that can be applied in the context of this study. DMAIC stands for the five phases of a Six Sigma project; Define (the problem), Measure (current data), Analyze (the data and identify root causes), Improve (the process) and Control (the process for maintaining the improved state) (Majeed, 2015).

Six Sigma provides process improvement with systematic sets of tools and techniques which reflects its managerial and technical aspects. The Six Sigma toolbox contains the seven tools of quality: control charts, histograms, check sheets, scatter plots, cause-and-effect diagrams, flowcharts, and Pareto charts; and the seven management tools: affinity diagrams, interrelationship diagram, tree diagrams, matrix diagrams, prioritization matrices, process decision program charts, and activity network diagrams (ThiBaoChau, 2017).

2.5.1.1. The DMAIC Methodology

Six Sigma is a complex and flexible system for achieving, sustaining and maximizing business achievements. It is characterized by the understanding of customers' needs and organized use of facts, data and statistical analysis results, and is based on management, streamlining and constantly creating new, ever better solutions with reference to all the processes taking place in the company. Furthermore, it is aimed at minimizing the costs of bad quality while simultaneously increasing customer satisfaction (Michal, 2017). The method is used to eliminate the causes of defects, losses they incur and any problems related to quality in the aspects of production, services and management. To solve these problems, the method employs quality tools and statistical techniques. When implementing the DMAIC method, a number of auxiliary quality improvement tools and methods are used. The improvement cycle using the DMAIC method consists of the following elements (Michal, 2017):

- **Define**

The defining phase must identify the following elements: determining the problem (description of the problem, time of occurrence), scope of the project (elements of the process), aim of the project (a tangible goal to achieve and sustain in the future).

- **Measure**

During the measurement stage parameters and places of measurement should be defined, i.e. the points of process quality and its costs along with a precise reflection of the actual state. Conducting measurements successfully requires a statistical outlook on the particular production processes and problems related to them. The measurement stage employs methods such as: descriptive statistics, summary charts, the SIPOC method and the process map.

- **Analyses**

During this stage of the methodology, by analyzing the particular parameters of the process able to determine the causes of the problem which will then need to be eliminated or fixed. The results obtained during the measurement stage are used in order to investigate the correlation between causes of defects and process variability sources. In order to identify the causes of process variability, which are a significant factor in defects creation, the PFMEA analysis, the Pareto - Lorenz chart and the Ishikawa diagram are often used.

- **Improve**

Improvement can otherwise be understood as engagement in the course of the production process, i.e. reduction of the defect rate. It consists in searching for and evaluating potential causes of process variability and investigating their correlations. Learning the multi-factor relations allows for achieving the desired results.

- **Control**

The control stage takes place after finishing the new process implementation phase. The fundamental goal of Six Sigma is the constant observation of the improvements introduced to maintain a desired level of quality. In this phase of the DMAIC the measurement system and potential verification process are repeated to confirm the improvement of the process. Afterwards, measures are taken to appoint control over the streamlined processes; usually a so-called control plan is created.

The DMAIC methodology is used for improving production processes, successfully contributing to the reduction of the number of non-compliant products and reducing production costs. The author of this elaboration decided to introduce this method to processes auxiliary to the production process, i.e. to the maintenance process. The maintenance process, as every other process, has its inputs, outputs, clients, suppliers and can be described using indicators, similar to the production process. The case presented pertains to the reduction of the maintenance cost.

2.5.1.2. DMAIC Tools

In Six Sigma there is no pre-defined sequence or set of tool that must be used in each phase. The selection of tools that are used for the different phases of DMAIC need to be based on logic, knowledge and the projects specific challenges (Gitte, 2016).

The five phases in the DMAIC-model has several tools that can be used in each phase, a few of them are showed in Table 2.2. The tools listed in the table are the ones used for this thesis and will be explained in further detail.

Table 2.2: Six Sigma and Lean tools used in different phases the project

Project Phase	Six sigma and lean tools
Define	VOC
	High level process map
Measure	Pareto charts
	Pie charts
Analyze	Pareto charts
	Cause and effect diagram
	ABC Equipment classification method
	Histogram
Improve	Standardized work flow
	JIT
	Material control
	Autonomous maintenance
	Preventive maintenance
	CMMS
Control	Check sheet

VOC – Voice of Customer

This represents all the needs and expectations that the customers have to the product or service. It provides important feedback and requirements that should be taken into considerations throughout the DMAIC-model. There are two different requirement that often is separated when speaking about VOC is the "need" which is what is absolutely required from the customer and becomes the CTQ and then there are "wants" which can be something the customer would like to have (Gitte, 2016). The reason for separating these is that the needs are important critical features while the wants are expectations beyond the needs.

The feedback is gathered through communication with the customer and there are three key VOC tools to use for this:

- Surveys
- Interviews
- Focus Group

Process Map

A process map is a detailed map that visualized how the process is carried out.

Pareto Chart

A Pareto diagram is a bar graph used to arrange information in such a way that priorities for process improvement can be established (Ylipaa, 2007). The Pareto Chart is used to visualize the importance of the differences between data-groups. The chart contains of both bars and a graph line, and they are ordered from the highest to the lowest related to their criticality. It is obvious that Pareto chart will help us to identify the most common categories of the cause of defect for example 80 per cent of the defects will arise from 20 per cent of the causes. These observations have become known as part of Pareto's Law or the 80/20 rule (Zafeirios, 2012).

Cause and effect

Dr. Kaoru Ishikawa developed a graphical tool that is used to identify and display possible variation causes in any given process. This graphical tool is called by several names like Ishikawa diagram, the cause and effect diagram and the fishbone diagram (Muhammad, 2010).

This diagram narrows down the scope for the analysis of the problem. Categories which are common for identification of potential variation sources of root cause include people, process, technology, equipment, material, and environment.

Cause and effect diagrams are qualitative nature and with the help of brainstorming we can have number of possible causes for the problem.

2.5.2. Lean Maintenance

Ricky Smith defines Lean maintenance as 'a proactive maintenance operation employing planned and scheduled maintenance activities through total productive maintenance (TPM) practices using maintenance strategies developed through the application of Reliability Centered Maintenance (RCM) decision logic (Mulugeta, 2009).

They are supported by a distributed, Lean maintenance/MRO (Maintenance, Repairs, Operations) store room that provides parts and materials on a just-in-time (JIT) basis, backed by a maintenance and reliability engineering group that performs root cause failure analysis (RCFA), failed part analysis, maintenance procedure effectiveness analysis, predictive maintenance (PdM) analysis, and trending and analysis of condition monitoring results' (Mulugeta, 2009). The key in the lean philosophy is to answer the question, "How do we reduce waste?" One of the answers to this question is improvement of equipment reliability and increase

of efficiency and effectiveness of maintenance activities (DrInz). Defined lean maintenance as delivery of maintenance services to customers with as little waste as possible. This promotes achievement of a desirable maintenance outcome with fewest inputs possible. Inputs include: labor, spare parts, tools, energy, capital, and management effort. The gains are improved plant reliability (availability) and improved repeatability of process (less variation). The characteristic of lean thinking, associated with maintenance to improve efficiency and reduce waste, is the use of such tools as: VSM, visual displays (e.g. 5S), kanban, kaizen (i.e. continuous improvement), Six-Sigma quality, setup time reduction and preventative maintenance (DrInz).

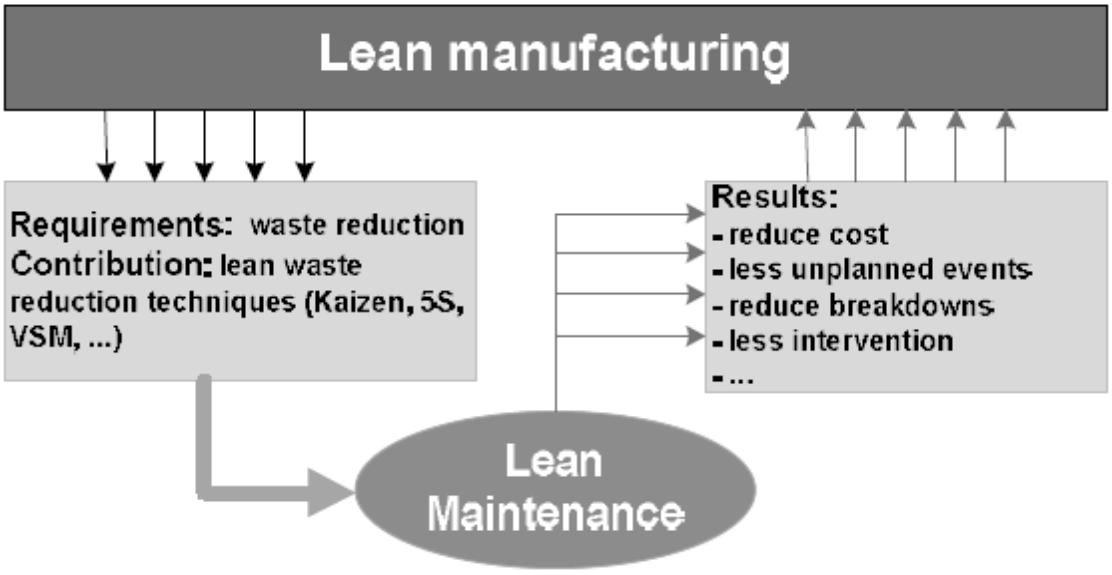


Figure 2.4: Lean manufacturing and maintenance (DrInz).

2.5.5.1. Lean Tools and Techniques

The key elements of a Lean maintenance method are visual management systems (VMS), the 5S method (sort, streamline, shine, standardize and sustain), Value Stream Mapping (VSM), proactive, planned and scheduled, total productive maintenance, empowered (self-directed) action teams, Kaizen improvement events, autonomous maintenance, multi-skilled maintenance technician, standardized work flow, work order system, computer managed maintenance system, distributed, lean maintenance/MRO storeroom, parts and materials on a just-in-time basis, maintenance and reliability engineering group (Orlando, 2017). Some of the lean tools are discussed below.

Standardized Work Flow

Standardized work is the well-organized method in Lean principle for producing the best in class quality product. Standardized work is essential to have in all repeated and critical processes. Standardized work helps in improving the product quality and in improving the Overall Equipment Efficiency (OEE). Standardized work helps in identifying the process abnormalities. If the process done by two different operators or observed an inefficient process sequence, develop the work standard. Introduction of new process or a tool or equipment will follow the steps of developing the work standards and train the employees on how to use the tool or equipment or to work in the change process. Work standards will always require a format or a template to develop with documentation numbers.

Standardized work is a mistake-proofing work methodology; it brings out uniformity in the work process sequence even when different people work at different time (Sherif, 2015).

Material Control

Spare parts Management plays an important role in achieving the desired plant availability at an optimum cost. Presently, the industries are going for capital intensive, mass production oriented and sophisticated technology. The downtime for such plant and machinery is prohibitively expensive. It has been observed in many industries that the non-availability of spare parts, as and when required for repairs, contributes to as much as 50% of the total downtime (Sherif, 2015). Also, the cost of spare parts is more than 50% of the total maintenance cost in the industry. It is a paradox to note that the maintenance department is complaining of the non-availability of the spare parts to meet their requirement and finance department is facing the problem of increasing locked up capital in spare parts inventory. This amply signifies the vital importance of spare parts management in any organization.

Every organization should proceed systematically and establish an effective spare parts management system. Codification helps the organization minimizing duplication of spare parts stocking thereby reducing inventory, aids the accounting process and facilitates the computerization of spare parts control systems. The inventory analyses carried out on the basis of different characteristics of the spare parts, such as annual consumption value, criticality, lead time, unit cost and the frequency of use; help the company in establishing suitable policies for selective control. This also helps in focusing our efforts on real problem areas (Vinicius, 2017).

For the successful spare parts management, it is essential to analyze the spare parts inventory based on various characteristics such as the frequency of issues, the annual consumption value, the criticality, the lead time and the unit price (Vinicius, 2017).

Just-in-Time of MRO Item

JIT is a method whereby the production lead time is greatly shortened by maintaining the conformity to changes by having "all processes produce the necessary parts at the necessary time and have on hand only the minimum stock necessary to hold the processes together" (Sugimori*et al.*). The most important factors that create a foundation for implementing just-in-time are the pull system. Taking a completely different approach from American traditional mass production method using push system as a core, Toyota decided to implement the pull system where replenishment of materials and goods is triggered at a certain level of consumptions (ThiBao, 2017).

Computer Maintenance Management System (CMMS)

Cost reduction within the maintenance organization does not concern to reduce the quality or the level of service. It concerns an increased control of the maintenance organization and also related areas. In order to control the maintenance organization properly information about occurring events are needed. To gather and analyze data manually requires a tremendous amount of both time and effort. Due to this, many companies develop and use computer programs concentrated on this. These programs, or systems, are called computerized maintenance management systems (CMMS) and they are designed to gather all data related to maintenance and to file it in the history of corresponding asset (Gustav, 2012).

The development of test equipment and computerized maintenance management systems (CMMS) has according to (NASA, 2008) made it possible to:

- Track and analyze the history of equipment as an aid of determining life-cycle cost and failure patterns.
- Determine the actual condition of equipment without time-based techniques which base the probability of failure on appearance and age instead of the equipment's condition.

Applications of CMMS Systems

Speed is one major advantage that CMMS have compared to manual systems. Other disadvantages with manual systems are communication problems, misplaced data and large file cabinets, which are reduced with CMMS.

In Figure 6 below are some advantages which are provided by the features included in CMMS presented.

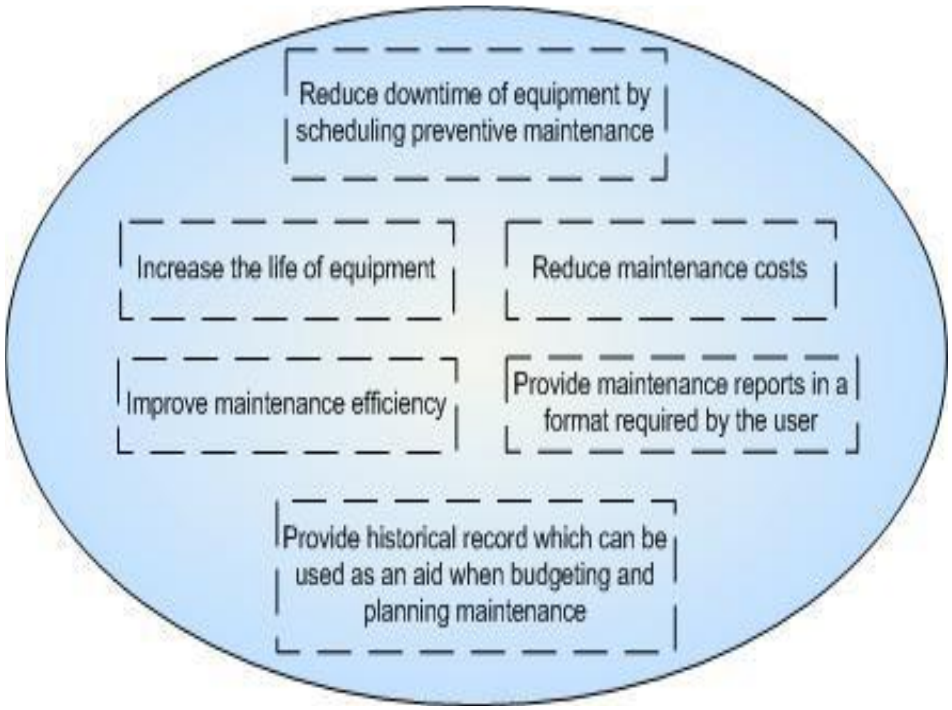


Figure 2.5: A presentation of some advantages which are provided by the features included in CMMS (Gustav, 2012).

Autonomous Maintenance

The machine or process operator know his/her equipment and can immediately catch information from the equipment and detect symptoms or abnormalities. Before the breakdown occurs there is a symptom, the breakdown is a result from the growth of a minor defect. It is not possible for the maintenance craftsmen to detect and cover all the breakdown symptoms. The equipment need to be checked for symptoms to eliminate breakdowns. The operators cannot help maintaining equipment unless they know how to do it (Sasaya, 2009).

2.5.3. The Synergisms of Lean and Six Sigma Methods

Lean Six Sigma, result of the fusion of Lean and Six Sigma, integrates all the strong points of the two methodologies and has all their advantages. Lean Six Sigma drives to process improvement, saving costs and increasing business competitiveness, focusing on customer and based on management commitment and employee engagement (Alexandra, 2017).

Six Sigma can help in developing skills, improving knowledge and employee morale and the ability to use a wide range of tools, techniques and has the following advantages: Establishing zero defaults targets, creating the DMAIC process improvement cycle, and intensive use of statistics and data to make managerial decisions and reduce process variation (Vinicius, 2017). The main difference between Lean and DMAIC is that Lean projects can use qualitative and quantitative analysis of root causes analysis, such as the five whys, cause and effect diagrams, Failure mode and effects analysis (FMEA).

However, by focusing on process improvement and variability reduction, Six Sigma programs do not guarantee a sustainable competitive advantage, and mechanisms need to be developed that address innovation and product differentiation, the pattern of change in the customer base, and uncertainty Environmental, while improving organizational processes, considering radical changes and the formation of new markets and / or customers (Vinicius, 2017).

Lean Six Sigma combines lean methods and Six Sigma, using specific DMAIC processes to provide companies with better speed and lower variability to increase customer satisfaction (Barraka, 2013).

The first phase in DMAIC process is to define project objectives and customer needs. The second phase is to measure the current process performance as well as quantifying the problems. The third phase is to analyze the process and find the causes of problems, particularly the root causes. The fourth phase is to improve the process, i.e. correcting the causes of defects and reducing process variability. The final phase is to control the process and maintain the improved performance. These five phases can assist Lean Six Sigma teams to systematically and gradually develop process rationalization, starting with defining the problem and then introducing solutions targeted to the fundamental causes, so constructing the optimal implementation method and ensuring the sustainability of solutions (Barraka, 2013).

According to a paper done by Antony which involves opinions of leading academics and practitioners about the similarities and differences between Lean and Six Sigma, it is undeniable

that an integrated approach of the two would produce extraordinary and long lasting results. On the report of his work, Lean and Six Sigma have some common characteristics as summarized as follows:

- Both offer complementary tool sets and require intense learning of those tools and techniques;
- Both are company-wide process improvement strategies and help identify opportunities for improvements;
- Both enhances problem solving capability of people;
- Both need management's support and engagement;
- Both place focus on customers' need and aim at delivering highest value to the customers as well as the organization;
- Both use multi-disciplinary team;
- Both can be applied in non-manufacturing environments.

On the other hand, one lacks features that can be complemented by the other (Antony, 2011).

- Lean focuses on eliminating wastes and other non-value-adding activities to improve process efficiency, while Six Sigma aims at enhancing process effectiveness through elimination of variation;
- Lean's tools are simple and straight forward that focus on finding quick solutions, while Six Sigma has more complex and statistical tools;
- Lean is useful for day-by-day improvement activities, while Six Sigma is good for more long-term, strategic and complex projects;
- Six Sigma offers statistical and data-driven approach which Lean does not have;
- The utilization of Six Sigma brings better bottom line improvements with the reduction of cost of poor quality items, while Lean does not deliver such dramatic financial results;
- Six Sigma has clearer and better structured approach with DMAIC method which helps its practitioners go through process improvement in a clear manner and order, while in Lean it's difficult to understand which tools to use at what times;
- Lean tools are easily adopted by people of all levels from shop-floor workers to top managers, while Six Sigma tool sets require years of training and development therefore usually perceived by managers with advanced knowledge and capability;
- Six Sigma's implementation needs more investment than that of Lean;

- By using Lean, practitioners look for more organizational explanation for problems, while using Six Sigma help them seek opportunities to analyze the problems in more statistical and rational ways.

Lean and DMAIC, can be integrated in order to form a more powerful tool than any other is alone, since practically all Lean concepts integrate well with any project DMAIC, regardless of size or scope, and root causes analysis is the common cross-point between these approaches (Vinicius, 2017).

Thus, the LSS incorporates the principles of speed and immediate action of the Lean with the vision Six Sigma of quality without defect and reduction of the impact of the variation in the times of queue. From this, Lean Six Sigma attacks the hidden costs of complexity and is a mechanism that seeks the engagement of all for joint reach and without trade-offs of quality, speed and cost (George, (2002).

It is essential to merge the two methodologies to reduce cost and complexity. Just as Lean cannot statistically control a process, Six Sigma alone cannot dramatically improve process speed or reduce invested capital (George, (2002).

Separately, Lean and Six Sigma methodologies often fail to lead to results that achieve the dramatic improvements that organizations desire. Though Six Sigma is adept at identifying and eliminating defects, it does not address how to optimize the system by improving process flow and lean methodologies, on the other hand, lack the statistical analysis required to achieve a truly "lean" system (G.Muthukumaran, V.S.K.Venkatachalapathy and K.Pajaniradja, 2013).

By combining the Lean and Six Sigma methodologies, L6σ aims to achieve total customer satisfaction and improved operational effectiveness and efficiency by removing waste and non-value added activities, decreasing defects, decreasing cycle time and increasing first pass yields (G.Muthukumaran, V.S.K.Venkatachalapathy and K.Pajaniradja, 2013). The objective of combining the two major techniques is to reduce the cost, irrespective of the product and the industry.

2.6. The role of purchasing in maintenance cost reduction

Management can have different views on the importance of purchasing and this will affect the role of purchasing within a company. Purchasing as an operational function will be evaluated by management on how well it handles things like order backlogs, purchasing administrative lead times, number of orders issued, etc (Henric, 2006). If purchasing is looked upon as a commercial function, the management is aware of its potential to primarily save money for the company. A good example of this is when management sets targets together with the purchasers to try to lower prices or costs. The impact of purchasing has increased dramatically in recent years as the value of purchased inputs has risen. Therefore purchasing directly affects costs and quality while influencing a firm's ability to compete on delivery, flexibility and innovation.

The role of purchasing in this thesis is defined as the main activities that the purchasing function conducts. Putting too much pressure on prices may convince the purchasers to purchase the wrong products, in terms of both bad suppliers and supply condition but also lower quality products.

Finally purchasing can also be seen as a strategic business function within the company, which means that the purchasers are almost on the same level as the top management. The purchasers are being evaluated upon many aspects, such as; number of changes in the supply base, number of new suppliers being contracted and purchasing's contribution to the savings realized (Henric, 2006).

Purchasing process concerning wholesaling companies consists of six activities, which are visualized in figure 2.8. The first four steps, called the initial or tactical purchasing activities, are primarily of a technical and commercial nature. The remaining two steps are referred to as the ordering activities, which have a more logistics and administrative character.

However, in order for the company to be effective, purchasing activities should be closely linked and interrelated to these materials activities.

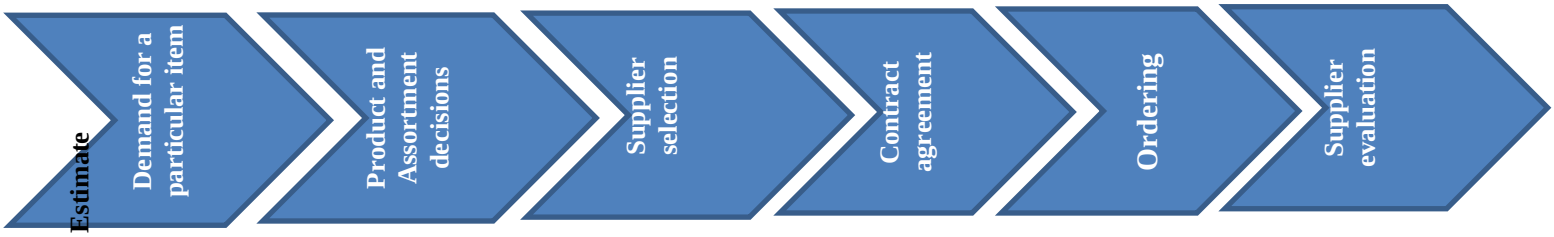


Figure 2.6: The purchasing activities (Henric, 2006).

2.7. Maintenance and Purchasing Process of the Case Company

2.7.1. The Maintenance Activity

The current equipment and machinery maintenance activities of the company consist of both preventive and corrective maintenance. But the corrective maintenance activity highly dominates the preventive activity. That means the breakdown work highly dominates, more than 85%, of the total maintenance activity in the year. This shows that, the existing maintenance planning system of the company cannot decrease the frequent breakdown of the machinery. The reason should be either the plan does not consider factors for interval of inspection, or the planned activities are not well practiced. But the main duty of the maintenance department in the company is repairing the failed machine not preventing or inspecting machines. Thus, this situation urges an implementation of a maintenance strategy, which improves this big number of breakdown.

The aim of this paper is reducing the maintenance cost of the company. The main cost which can be reduces are the factors that increase the maintenance cost of the company through identifying those factors discussed in the six sigma phase of the methodology. One way of reducing the maintenance cost is reducing machine breakdown. In this paper identified frequently failure machines and critical to production machine and based of their criticality and frequency of failure proposed maintenance strategies and develop a model through the use of lean maintenance principle to reduce machine breakdown as well as maintenance cost of the company.

2.7.2. Spare Part Request and Purchasing Procedure

In the current purchasing of spare parts and other auxiliary equipment process are time consuming, increase transport cost and increase the overall cost due to nonstandard purchasing process and the selection of supplier only decided by a single person the purchaser. The company is indirect relationship with the supplier and this may causes the company to purchase in high cost due to purchaser skills and willingness to search the right suppliers.

The existing company purchase requisition and the purchasing process are shown below in the figure 2.7.

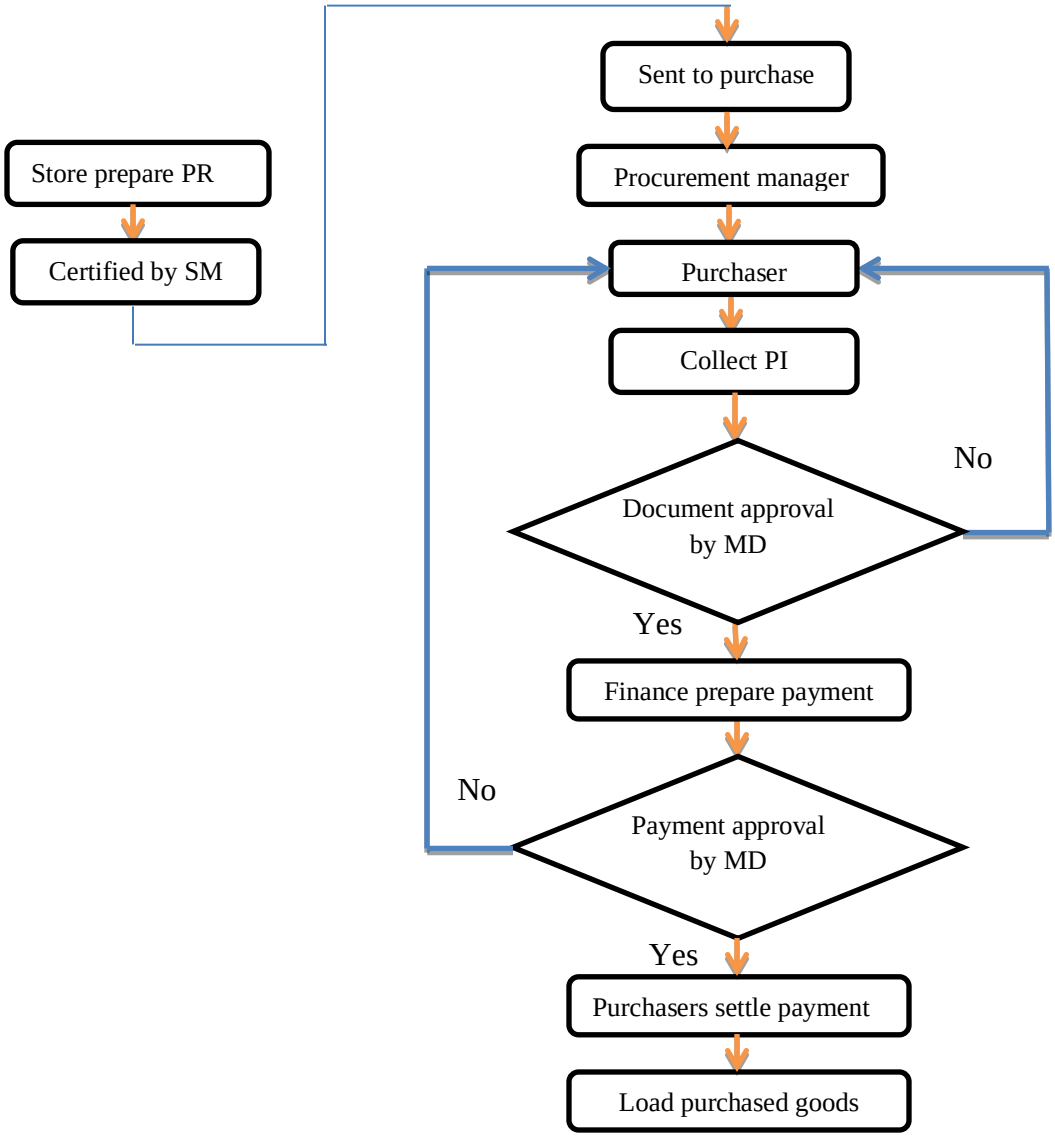


Figure 2.7: Existing purchase requisition PR and purchasing process of the company

2.8. Literature Summary and Gap

This section focus on the investigation of the gaps in current maintenance approach and to provide practical insights and recommendations to maintenance strategy and develop a model that helps to reduces maintenance costs based on case studies in related industries.

The following literatures which are extracted from different authors are important to have better understanding on maintenance system, and were help to identify the gap easily.

2.8.1. Literature summary

Table 2.3: Summary of Literatures

Authors & Date	Title	Objective	Methods	Finding
Adnan Al-Bashir 2012	Implementation of Six Sigma on corrective maintenance	Increase the availability of medical equipment by reducing the down time of equipment during maintenance work	SIX SIGMA (DMAIC) approach	The downtime reduced by 35%
BarrakAlsubaie & Qingping Yang	Maintenance process improvement model by integrated LSS & TPM for service organization	To increase process performance and overall equipment effectiveness and improve the effective and efficient management of the vehicle fleet maintenance	LSS & TPM	A new model based on TPM and Lean Six Sigma has been presented to provide guidance and support for service organizations
GitteRussøKalsvik 2016	Performance Improving Using Six Sigma & lean	To reduce the cycle time in a maintenance process and identify an increasing factors and minimized or remove them	Six Sigma and Lean	Speeded up the process by; identify and removewaste in the maintenance process and give clear instruction on the sequence of the maintenance steps.

2.8.2. Research Gaps

Literature search identified different research works that have dealt with maintenance in relation to company's competitiveness and profitability (Mahlet, 2017). Most researches have done maintenance associated to productivity in order to solve those maintenance factors they retard the productivity like machines breakdown and focused on different maintenance approaches

using TPM, PM, CBM, RCM. Despite that the importance of maintenance impact on company's business is emphasized. There are different authors done on the maintenance process improvement and downtime cost analysis. They are mainly focus on reduction of machine breakdown and the availability of the machine to improve the productivity.

As showed table 2 that no much previous works have investigated on maintenance cost and its reduction strategies related to direct cost of maintenance. Therefore, this paper seeks to explore the factors increasing maintenance cost, critical and frequently failure machines, causes of machine breakdown and the maintenance, purchasing and financial management strategy of Ethiopia Tannery Share Company.

As discussed above maintenance cost consists of direct and indirect costs. Direct (visible) costs comprise factors such as direct labor, e.g. manpower, direct material, e.g. spare parts, and overheads, e.g. tools, transportation, training and methods. Indirect (invisible) costs are all the costs that may arise due to planned and unplanned maintenance actions, e.g., lost production costs, accidents, etc. And it is basically focus on analyzing the various factors that increase the maintenance cost of the organization like cost related to outsourcing maintenance, purchasing of spare parts, direct labor and training methods

In this research, six sigma and lean were used to identify measure, analyze, improve and control the major factors that increase the maintenance cost of Ethiopia Tannery Share Company. To achieve the objective of this paper integration of lean and six sigma maintenances strategies were used.

1. Analyses of the major factors and underlying causes that increase the maintenance cost of the case company

- Detail analysis of Spare parts and material cost
- Cost related to outsourced maintenance cost

2. Assess availability of maintenance cost reduction strategy in maintenance and other related departments like finance, spare part store and purchasing

3. Formulation of maintenance cost reduction strategy and develop a model that incorporate standard operation procedure in the purchasing of spare parts and outsourcing maintenance work. Therefore, the model that is developed in this paper addresses the above identified gaps

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Methodological Framework

All activities in research process do not always follow the same order nevertheless the relevant generic pattern is presented in figure below to this research.

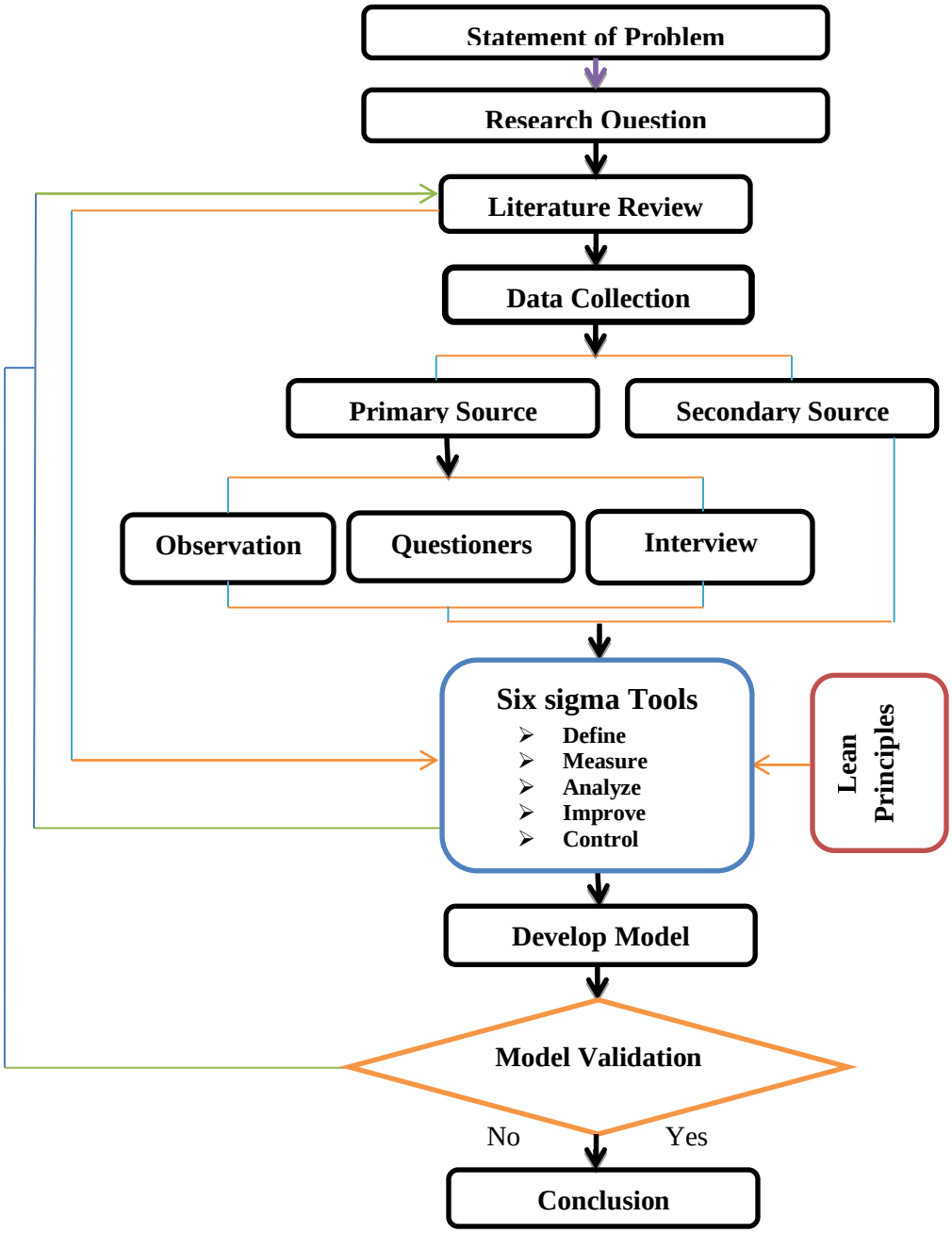


Fig 3.1: Methodological Framework according to researcher

3.2. Data Collection Methods

To achieve the aim of the study data were used based on both primary and secondary data sources.

The primary source was the main input for the study and data regarding the major factors increasing maintenance cost, critical and frequently breakdown machines, root cause of machines breakdown, the existing maintenance, purchasing process and other related issues and the data were collected through questionnaires, interview and physical observations.

The secondary sources were used includes relevant literatures, theories, records and documents such as books, researcher's papers and articles, internets, subject experts and published researches in order to analyze the maintenance cost, maintenance operation, strategies, methods and to arrive at a complete understanding of lean and six sigma methodology.

These sources were used to support the research to investigate the various maintenance problems, to develop the knowledge of the topic, to support the analysis and to propose appropriate improvement solution.

Data collections were used both qualitative and quantitative in nature. Quantitative means anything that exists in a certain quantity and can be measured. The methodology has a quantitative nature because there will be quantifiable measures of variables. However some of the data are may not be inherently quantitative that is they were not necessarily have to be expressed in numbers, and they are qualitative in nature. The data required for the study were identified and collected by communicating maintenance, finance and costing, spare part store and purchasing department of the case company. In this study used the following search engine or data base for the finding of different related literatures, researcher's paper, articles, journals and published papers. These are Ryerson library digital repository, Google scholar, open access thesis & dissertation (OATD), www.diva-portal.org and AAU institutional repository.

I. Physical Observation

More than 10 time observation are conducted to get information regarding the existing maintenance process, information flow, spare part management system, organization of the maintenance department, major cost factors area, types of spare parts required etc.

II. Survey Questionnaires

In this data collection method collect information about the existing maintenance management methods, strategies, spare part management, financial and cost management strategies and organization of the maintenance departments and their relationships. The questionnaire has five parts that cover the following topics.

Section I - Maintenance strategy: availability of maintenance strategy

Section II –Organization of the maintenance department**:** how the maintenance department organized manager, supervisor etc

Section III - Machinery categorizations, historical data organization and failure analysis: to identify how equipment are categorized based on critical to production, failure rate etc.

Section IV - Operator involvement and skill level of maintenance personnel: to identify involvement of operators in the maintenance of their machines and skill level of technicians.

Section V - Training program in maintenance**:** to identify availability of training program for operators, technician and supervisor.

Section VI- Out sourcing the maintenance work**:** to identify availability of standardized outsourcing procedure.

The target groups for the questionnaires are maintenance department managers, division heads and supervisor, finance managers, costing, accounting department.

The numbers of questionnaires are about 32 depending on the required data and their response. The questioners are distributed to 26 peoples and it was a response rate 80.7%.

III. Semi-structured Interview

A semi-structured interview was employed because this is useful for asking a set of questions to guide the conversation. Moreover, semi-structured interviews allow interviewees freedom to talk about what is of interest or importance to them. This can lead to a new and unexpected direction for a researcher to develop and explore new topics.

The interview methods used in this paper were semi-structured interviews. It allows the respondent to answer each question freely. The information collected were the various maintenance costs, causes of machine breakdowns, factor increasing maintenance cost and the purchasing methods of the case company. The numbers of interviews question are 24 and the interviewers are 12 peoples and the interview questioners are found in Appendix I.

3.3. Sampling Techniques and Sample Size

Sampling is defined as the process of selecting certain members or a subset of the population to make statistical inferences from them and to estimate characteristics of the whole population. The sampling techniques are random and nonrandom sampling. Probability samplings is sampling method that selects random members of a population by setting a few selection criteria. These selection parameters allow every member to have equal opportunities to be a part of various samples. Non probability sampling method is reliant on a researcher's ability to select members at random. For this study a judgmental non-random sampling technique is selected. This sampling strategy is more common in qualitative research. It is also possible to use this technique in quantitative researches. In judgmental sampling, the samples are selected based purely on researcher's knowledge and credibility. In other words, researchers choose only those who he feels are a right fit (with respect to attributes and representation of a population) to participate in research study.

Sample size: there are a total of 36 employees under maintenance department. 26 maintenance manager, division heads, supervisor and technician were participated for data collection. 10 finance and 5 purchasing departments' employees also participated. The total numbers of participants with the corresponding position are shown below in the table.

Table 3.1: Participants for data collection with their respective position

S.No.	Departments	Position	Number
1	Maintenance	Manager	01
		Division head	05
		Supervisors and Senior and junior technician	20
2	Finance	Finance Director	01
		Finance manager	01
		Finance assistance and accounting managers	03
		Senior accountant and costing	05
3	Procurement and logistics	Procurement and logistics manger	01
		Purchasers	04
Total number of participant			41

3.4. Lean six-sigma

As a methodology lean and six sigma were used for this study. Six sigma from the literature review understood that it contain statistical tools and techniques used for the analysis of certain problems. On the hand, lean used for reduction of variation and process improvement. To define measure, analyze and control process the six sigma tools were used. For the improvement of the identified gaps, problem and development of a model lean maintenance strategy were used. The lean and six sigma tools used for this study are shown in table 2.2 in the literature.

3.5. Validity Testing Method

Validity highlights the question whether an indicator actually measures what it is looking for. There are multiple approaches to pursue the validity of a concept and its data, below discussed used in in this paper to validate the method and the model developed.

Test has face validity if its content simply looks relevant to the person taking the test. It evaluates the appearance of the questionnaire in terms of feasibility, readability, consistency of style and formatting, and the clarity of the language used (Hamed Taherdoost, 2016).

According to face validity definition above the researcher try to validate the method and model developed in this study. The researchers evaluate the research method of the questioner through feasibility, readability, formatting and clarity of the language. Based on the results of the questioners and model developed the research methods used and the developed model are very feasible, readable and consistent in style and formatting and used a clear language. So that as per the discussion, the research method used and the proposed model is relevant and feasible because it addresses practical problems.

3.6. Ethical Consideration

The study considered some ethical issues. This are the respondent experts and others has the right to respond or not, the respondent experts and others has the right to participate or not, the study has inform the respondents the purpose of the questioner, purpose of the study, wellbeing of the study to themselves and the study not ask the name of the respondent to considers the confidentiality of the response. While conducting the study, emerging ethical issues has been considered and given attention. Before the collection of the data study get approval from the managing and finance director of the case company.

CHAPTER FOUR

4. DATA COLLECTION, PRESENTATION ANALYSIS AND DISCUSSION

4.1. Introduction

The DMAIC approach is applied in order to identify various factors that increase the maintenance cost and improvement areas in a maintenance process. Data collection was an essential part for carrying out the Six Sigma project. It was necessary to select which data to use. Once the project has been defined and the data has been selected and gathered the next step will be to analyze the data and to improve the process by applying Six Sigma tools and Lean principles. Lastly it is important to maintain which ever changes or measures that are for the suggested implementation based on the method.

Throughout this research, the various factors that increase the maintenance cost and causes of frequently breakdown machines are investigated.

The next step is to verify the kind of problems affecting the maintenance cost and downtime that influence the quality of service, using DMAIC methodology from Six Sigma and the analysis made using ISHIKAWA diagram, Pareto analysis, Voice of Customer (VOC), Process Map and SIPOC diagram.

4.2. Define Phase

As stated in the theory chapter first part of the DMAIC-model is to define the project. This project aims to propose maintenance cost reduction strategies and develop a model, and then apply Six Sigma methodology to determine the factors that increase the maintenance cost, frequently failure machine and causes of machine breakdown for the case ETSC.

By implementing the define phase it becomes absolutely clear that we need to describe the problem the best way otherwise there will be no chance that we can solve it. In the company which is the subject of this study the key factors that increase maintenance costs are increasing outsourcing maintenance work, nonstandard operation procedure in purchasing, frequently machine breakdown, high material and spare part consumption.

Our major issue of concern is identifying main factors that increase the maintenance cost and propose maintenance cost reduction strategies and develop a model. It is absolutely clear that we have to use a scientific approach to propose maintenance cost reduction strategies; therefore we need to have documented evidence about which factors are the major factors for increasing maintenance cost, which equipment are critical, what are the real/root causes of breakdown. And this was able to focus the effort on the specific factors that increase the maintenance cost and specific piece of equipment to analyze the root causes and propose corrective actions.

This was done through the use of both primary and secondary data sources shown in the methodological framework figure 3.1. The primary source used for the determination of the factors that increase the maintenance cost, identification of critical machines, frequently failure machine, root causes of frequent machine breakdown and other related issues are direct observation, interview and questionnaires.

The secondary source used are relevant literatures, theories and documents such as researcher's papers and articles, internets, and company records in order to analyze the maintenance cost, strategies, methods and to arrive at a complete understanding of lean and six sigma methodology.

I. Voice of the Customer

Maintenance improvement projects usually to deal with internal customers. In this case, the service (maintenance) provider is the technical department (e.g. spare part store worker, electrician, mechanics, purchaser, etc) and the customer is the production. To capture the Voice of the customer (VOC) was another difficult task which is accomplished. The tool used in the Define phase, Voice of the Customer (VOC), requires a meeting with the customer in order to identify important factors for the customer. The information needed for the VOC was gathered through a personal observation, survey, unstructured face to face interview and focus groups.

Moreover, the researcher becomes a customer in order to make an assessment of the personnel needs in the maintenance departments and to identify critical to quality characteristics (CTQs), which should be addressed by the outputs of process. For instance, take a glance at the following examples:

- Managing Director says: "The maintenance cost must be reduced".

  CTQ ⟹ Reduce purchasing of spare parts and other cost factors

- Finance Director Says: "Maintenance to be responsible for the increased repair cost".
  CTQ ⟹ To reduce the cost outsourcing maintenance work should be reduced
- Maintenance Manager says: "we need to use preventive maintenance to reduce breakdown".
  CTQ ⟹ Identifying of critical and frequently failure machines are a must

II. High Level Process Mapping

A process map is a detailed map that visualized how the process is carried out. It contains of different symbols that represent different actions. The following figure illustrates the core process which this project is focused on. It is not a detailed one and helps that everyone involved understand the suppliers (S), their input (I), the process (P), the output (O) and the corresponding Customers (C).

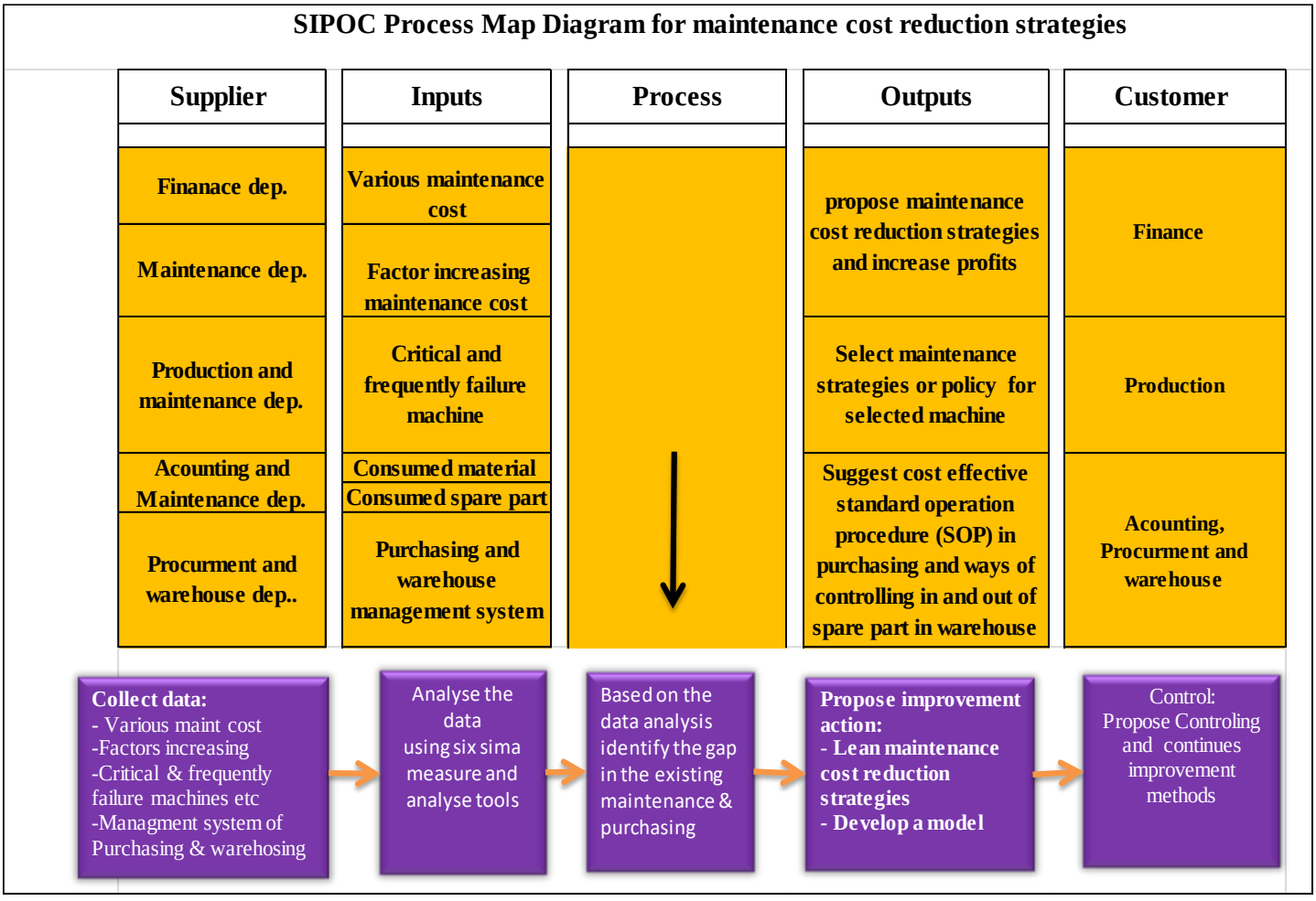


Figure 4.1: SIPOC map of the process

4.3. Measure Phase

There are two types of data that can be collected, quantitative and qualitative. The quantitative data was provide numbers and figures while qualitative was gave data which cannot be translated into numbers. Six Sigma is a type of method that depends on statistical data but it is also complemented by qualitative information through e.g. VOC and Fishbone figure. The combination of quantitative and qualitative data is favorable to better cover the whole picture of the maintenance process.

The planning of which data's to collect and how to collect them was based on the problem description for the Six Sigma project, i.e. to reduce the maintenance costs for the maintenance process. Based on this, the data that would be needed are factors increasing maintenance cost, list of critical machines, frequently failure machines, causes of failure and their breakdown time.

All the above factors are needed to be collected and translated into cost to reveal the gap between current and future state and also to see which factors are needed higher priority for further analysis and improvement.

4.3.1. Maintenance Cost of ETSC

Since this study is focused in maintenance, the maintenance cost of the company is selected for the analysis. The maintenance cost of the company is recorded in the annual report as shown below.

Table 4.1: Average maintenance cost comparison of the company

Maintenance cost	Maintenance cost in Birr			Average cost in Birr	Average Cost in %
	2016	2017	2018		
Employee wage	1,711,035.29	1,549,612.24	1,177,652.00	1,479,433.18	24
Spare parts	3,016,089.92	3,330,193.12	5,612,292.82	3,986,191.95	66
Over time	644,943.21	566,290.99	605,290.64	605,508.28	10
Total	5,372,068.42	5,446,096.35	7,395,235.46	6,071,133.41	100

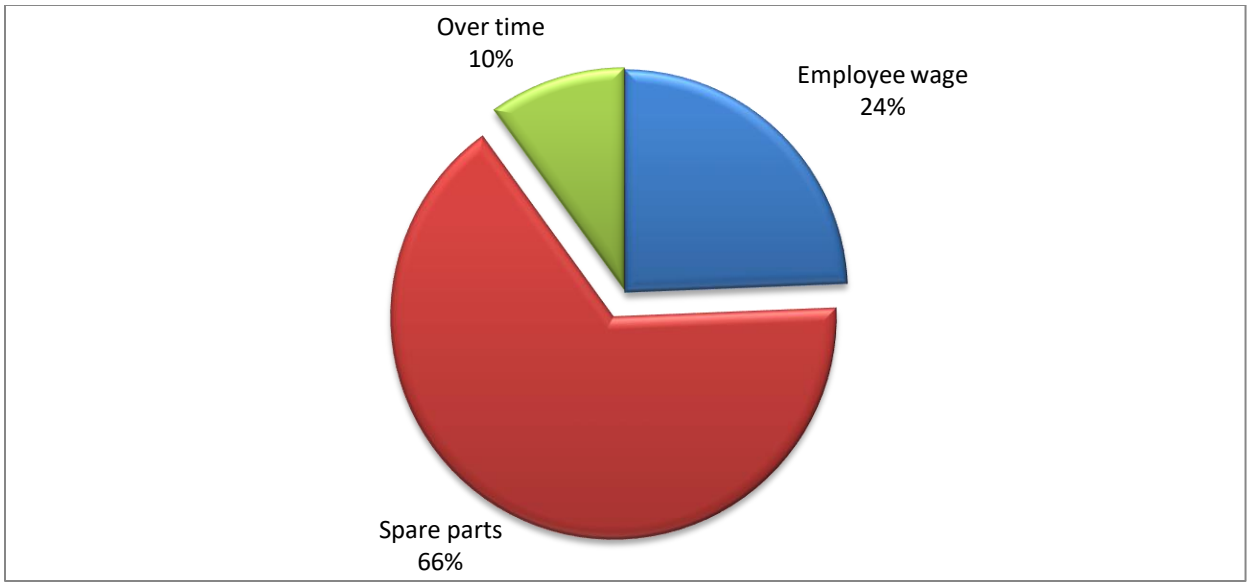


Figure 4.2: Average maintenance cost comparison of the company

As we can see from the figure the spare part cost of the company increase year to years and it account an average of 66% of the total cost and to analyze the indirect cost loss due to breakdown the company have not well organized data. So in this paper further analyzed the spare part and out sourcing maintenance cost quantitatively.

In order to test several factors in the Analyze phase it would be necessary to consider the whole spare parts and outsourcing maintenances costs of the company. Therefore, it was decided to gather the spare parts types and outsourcing maintenance work and its corresponding costs.

Due to large amount of work of data collection relative to the different spare parts types it was decided to categorize the cost of spare parts and out sourced maintenance work into sixteen and the last other is include more than 194 items.

These costs are direct maintenance cost of the company this are spare part cost and outsourcing maintenances cost shown below the in table for the years 2016, 2017, 2018 and four months of 2019 data respectively.

A Pareto chart was applied to determine which spare parts and maintenance work in the ETSC to focus on. The Pareto chart was made by categorizing every spare parts and outsourced maintenance work and plotting the cost data of three consecutive years and four months in different charts. The corresponding Pareto diagram are showed in Figure below, the few vitals inside the rectangle are a high cost factors relative to other.

Table 4.2: Spare part and outsourced maintenances work cost for ETSC in 2016

S.No.	Item Type	Quantity	Amount
1	Bearing	209	888,557.72
2	Contactors, breakers, relays, F. lamps	1877	519,409.41
3	Pipes and fittings	294	166,255.43
4	Electrodes	153pkt	99,603.41
5	Belts and seals	347	52,365.57
6	Hoses		12,131.56
7	Sheet metals and angle iron	98	88,527.30
8	Copper wire	19roll	134,091.80
9	Round bar of bronze, brass and cast iron	56.35m	124,518.00
10	Electrical cable and wires		63,529.46
11	Bolt and nuts	3202	47,366.50
12	Grinding tools and disks	48	18,365.22
13	Outsourcing works		563,904.75
14	chains	62m	23,970.00
15	Volkanizer kit	3	10951,52
16	Otheres (194 items)		516,645.47
Total Amount			3,319,241.60

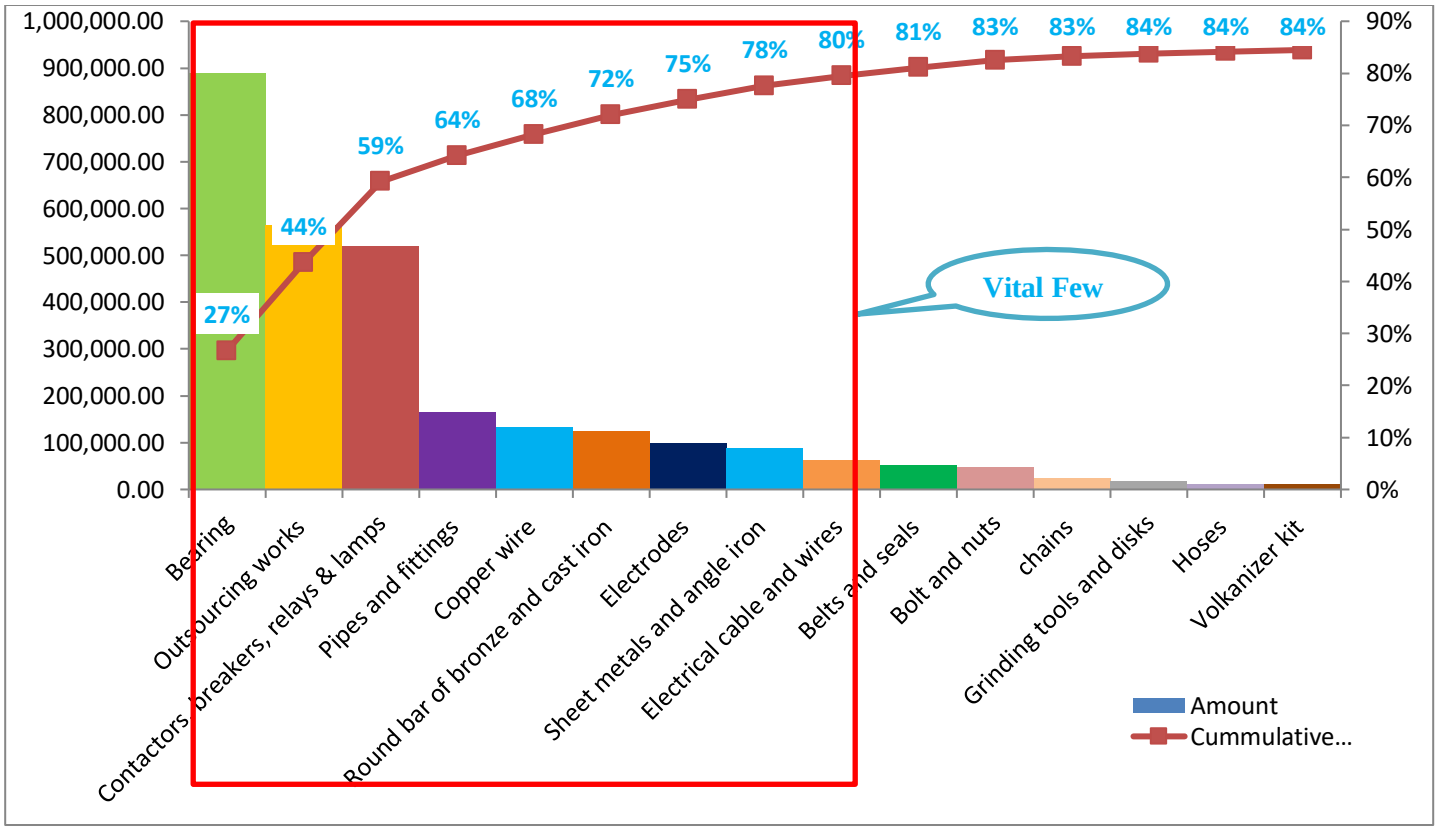


Figure 4.3: Pareto diagram for spare parts and outsourced maintenance work cost in the year 2016.

Table 4.3: Spare part and outsourced maintenances work cost for ETSC in 2017

S.No.	Item Type	Quantity	Amount
1	Bearing	264	596,268.21
2	Contactors, breakers, relays,F. lamps	940	266,529.40
3	Pipes and fittings	472	405,722.55
4	Electrodes	173pkt	136,673.53
5	Belts and seals	269	54,252.38
6	Hoses		59,851.66
7	Sheet metals and angle iron	174	125,432.52
8	Copper wire	19roll	144,759.27
9	Round bar of bronze, brass and cast iron	158m	48,939.00
10	Electrical cable and wires		199,405.00
11	Bolt and nuts	1411	23,126.00
12	Grinding tools and disks	44	15,810.52
13	Outsourcing works		271,982.09
14	chains	31m	65,400.00
15	Volkanizer kit	5	16,899.99
16	Otheres (416 items)		585,037.80
Total Amount			3,016,089.92

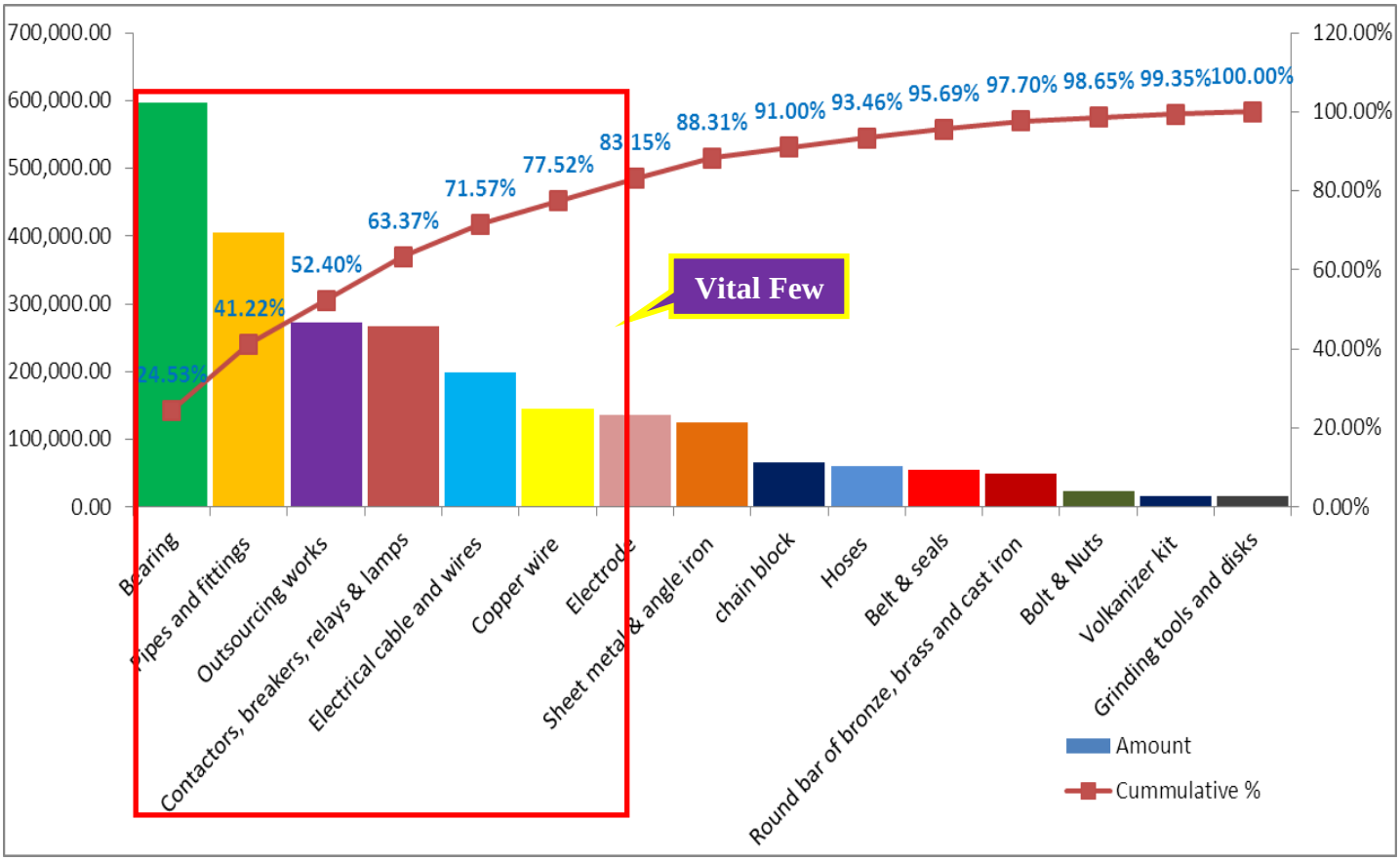


Figure 4.4: Pareto diagram for spare parts and outsourced maintenance work cost in the year 2017

Table 4.4: Spare part and outsourced maintenances work cost for ETSC in 2018

Item Type	Amount	Cumulative amount	%	Cumulative %
Contactors, breakers, relays,F. lamps	367,548.80	367,548.80	20.11%	20.11%
Outsourcing works	341,041.04	708,589.84	18.66%	38.76%
Otheres (128 items)	302,949.19	1,011,539.03	16.57%	55.33%
Sheet metals and angle iron	180,826.10	1,192,365.13	9.89%	65.23%
Electrodes	175,090.00	1,367,455.13	9.58%	74.80%
Round bar of bronze, brass and cast iron	138,937.00	1,506,392.13	7.60%	82.41%
Bearing	118,269.00	1,624,661.13	6.47%	88.88%
Pipes and fittings	102,364.00	1,727,025.13	5.60%	94.47%
Belts and seals	43,413.23	1,770,438.37	2.37%	96.85%
chains	32,000.00	1,802,438.37	1.75%	98.60%
Copper wire	17,518.50	1,819,956.87	0.96%	99.56%
Hoses	5,772.17	1,825,729.04	0.32%	99.87%
Grinding tools and disks	1,650.00	1,827,379.04	0.09%	99.96%
Bolt and nuts	650.00	1,828,029.04	0.04%	100.00%
Electrical cable and wires	0.00	1,828,029.04	0.00%	0.00%
Volkanizer kit	0.00	1,828,029.04	0.00%	0.00%

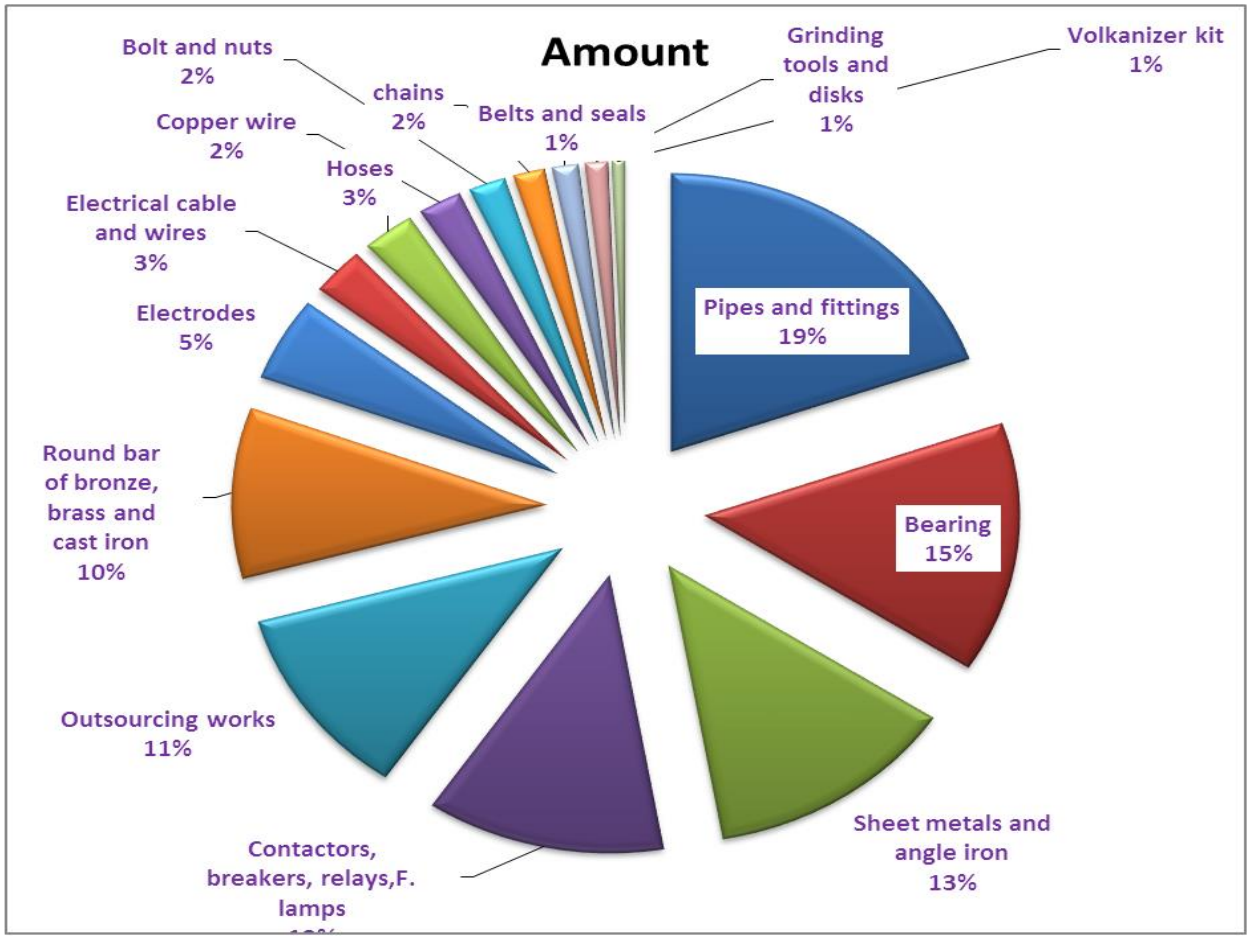


Figure 4.5: Pie chart for spare parts and outsourced maintenance work cost in the year 2018

Table 4.5: Spare part & outsourced maintenances work cost for ETSC from first January to the end of April 2019

Item Type	Amount	Cummulative amount	% Individual	Cummulative %
Contactors, breakers, relays,F. lamps	367,548.80	367,548.80	24.10%	24.10%
Outsourcing works	341,041.04	708,589.84	22.36%	46.46%
Sheet metals and angle iron	180,826.10	889,415.94	11.86%	58.32%
Electrodes	175,090.00	1,064,505.94	11.48%	69.80%
Round bar of bronze and cast iron	138,937.00	1,203,442.94	9.11%	78.91%
Bearing	118,269.00	1,321,711.94	7.75%	86.67%
Pipes and fittings	102,364.00	1,424,075.94	6.71%	93.38%
Belts and seals	43,413.23	1,467,489.18	2.85%	96.22%
chains	32,000.00	1,499,489.18	2.10%	98.32%
Copper wire	17,518.50	1,517,007.68	1.15%	99.47%
Hoses	5,772.17	1,522,779.85	0.38%	99.85%
Grinding tools and disks	1,650.00	1,524,429.85	0.11%	99.96%
Bolt and nuts	650.00	1,525,079.85	0.04%	100.00%
Electrical cable and wires	0.00	1,525,079.85	0.00%	100.00%
Volkanizer kit	0.00	1,525,079.85	0.00%	100.00%

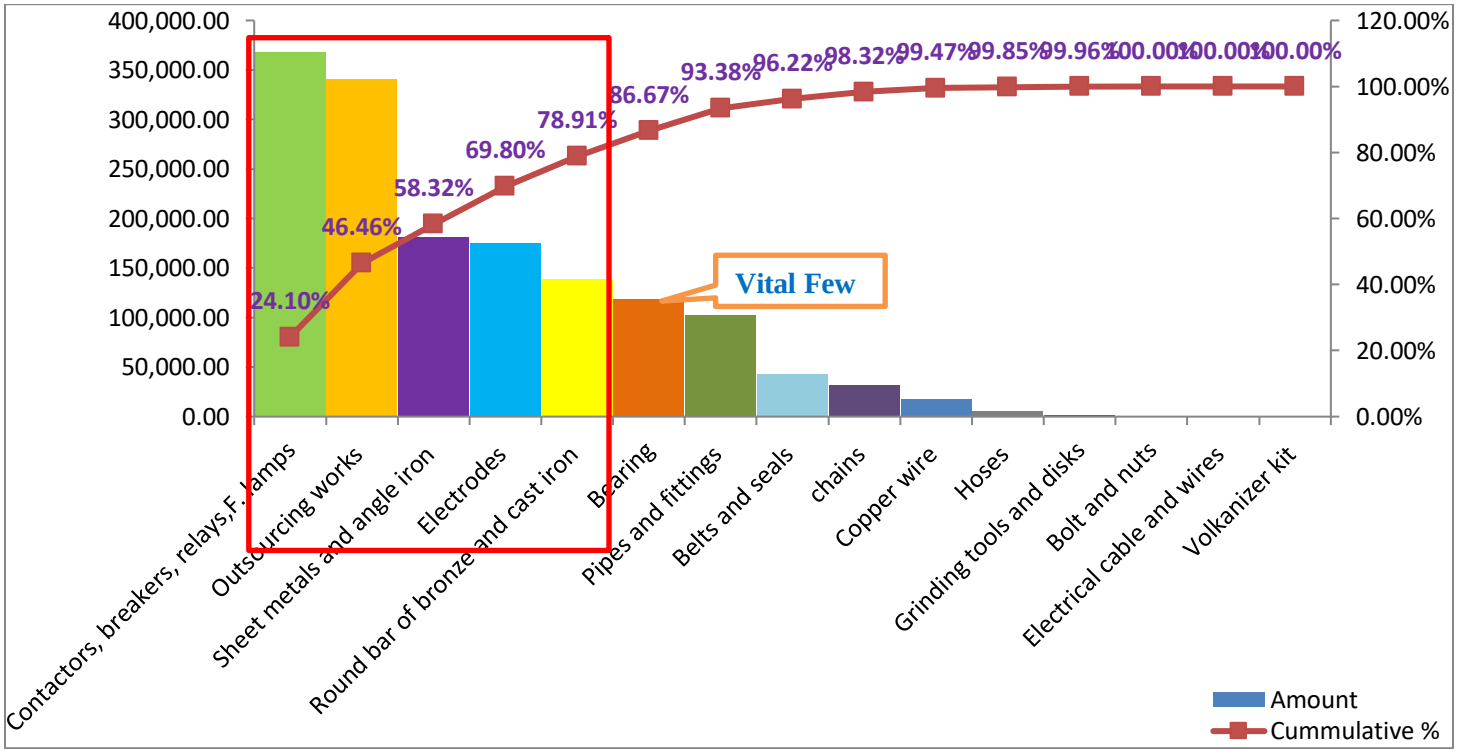


Figure 4.6: Pareto chart for spare parts and outsourced maintenance work cost for ETSC from first January to the end of April 2019

Table 4.6: List of critical machines for ETSC

Critical Machine	Respondent No	Cumulative	% Cumulative	%
Overhead crane	4	4	15%	15%
Retanning drum	4	8	30%	15%
Fleshing	3	11	41%	11%
Vaccum drier	3	14	52%	11%
Samming	2	16	59%	7%
Shaving	2	18	67%	7%
Measuring	2	20	74%	7%
Setting	1	21	78%	4%
Spray	1	22	81%	4%
Spliting	1	23	85%	4%
Staking	1	24	89%	4%
Buffing	1	25	93%	4%
Sun set machine	1	26	96%	4%
Sincro sta------cking	1	27	100%	4%

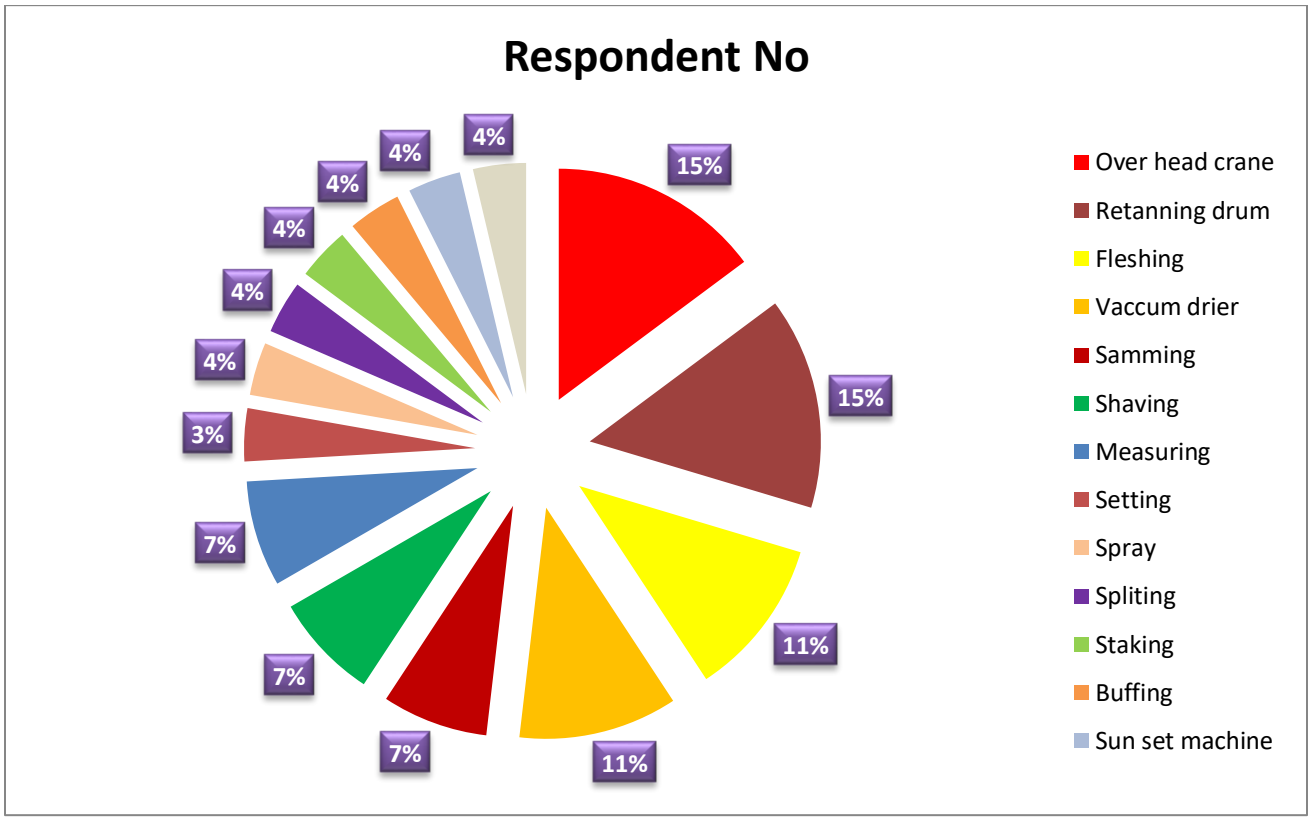


Figure 4.7: Pie chart for Critical machines of ETSC

Table 4.7: List of frequently failure machines for ETSC

Frequently failure machine	Respondent No	Cumulative	% Individual	% Cumulative
Fleshing	9	9	17.6%	17.6%
Shaving	7	16	13.7%	31.4%
Overhead crane	6	22	11.8%	43.1%
Vaccum drier	6	28	11.8%	54.9%
Splitting	5	33	9.8%	64.7%
Measuring	4	37	7.8%	72.5%
Samming	4	41	7.8%	80.4%
Retanning drum	2	43	3.9%	84.3%
Spray	2	45	3.9%	88.2%
Ironing	1	46	2.0%	90.2%
Buffing	1	47	2.0%	92.2%
paddle machine	1	48	2.0%	94.1%
Slow Comp macnine	1	49	2.0%	96.1%
Boiler	1	50	2.0%	98.0%
Mosterden	1	51	2.0%	100.0%
Total	51			

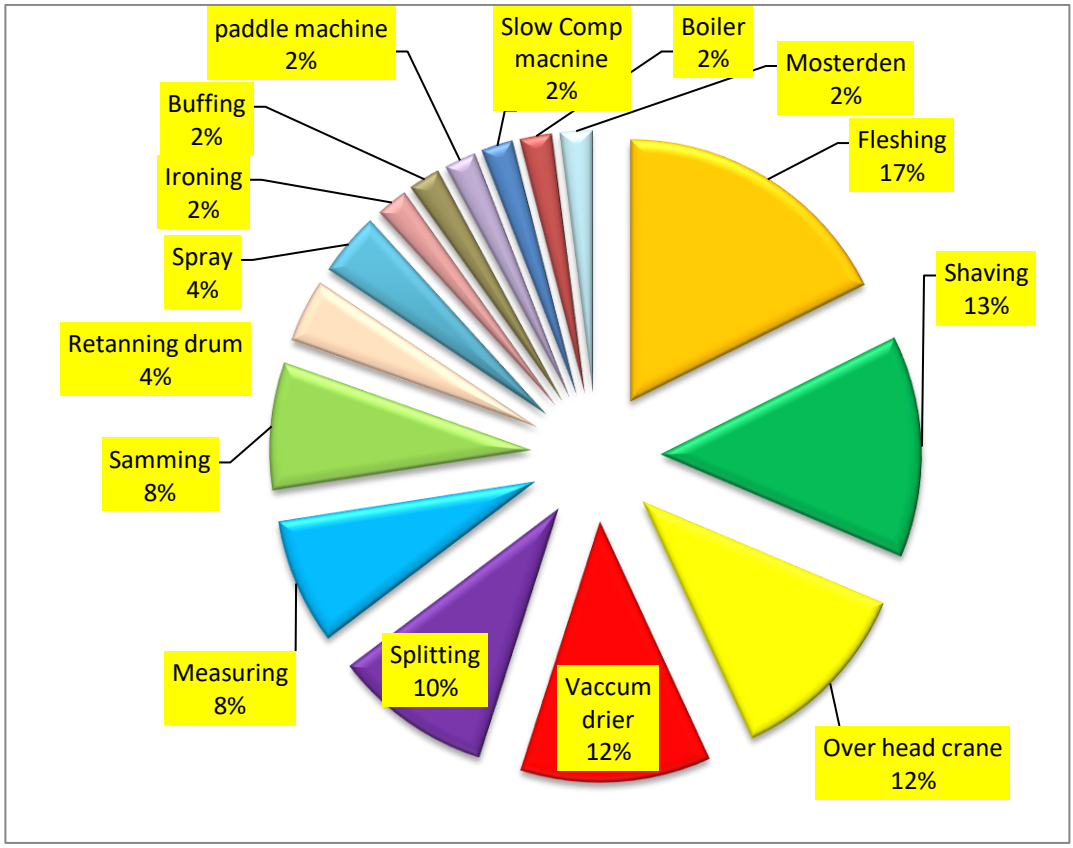


Figure 4.8: Pie chart for frequently failure machines of ETSC

4.4. Analyze Phase

This is, perhaps, the most important phase of the study since it verifies the root causes of defects. The data collected in the Measure step is analyzed in detail, cause and effect relationships were explored. The first stage involves analyzing the process and discovering what the existing process knowledge says. The second stage copes with the analysis of data and the establishment of relationship between the process output (symptom/defect and the cause of it).

4.4.1. The Major Factors and the Underlying Causes that Increase the Maintenance Cost

From the data collected some factors were found to be more likely to influence the variation in the process than others. In the measure phase the four year cost distribution of the various spare parts Pareto chars were plotted for each years. The major cost factors are a little be different in each years and the combined and average cost data of the Pareto charts are plotted below.

The red dotted line shows in the combined Pareto chart and the vital few inside the red rectangle from average Pareto chart plot are contribute 84% of the total spare part cost of the company. Consequently, those six spare part types and outsourced maintenance work were selected for further investigation.

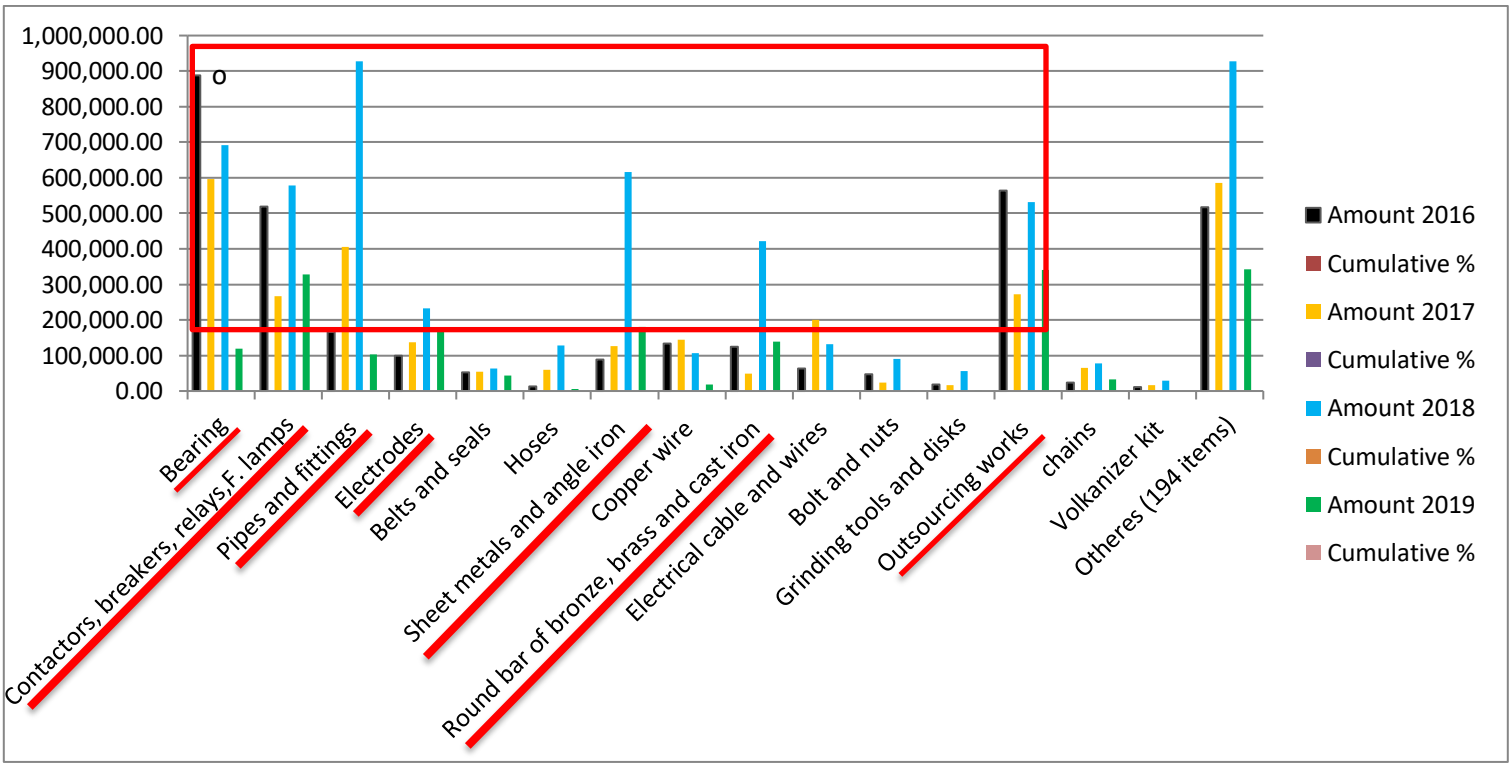


Figure 4.9: Pareto chart for four years combined spare parts and outsourced maintenance cost

Table 4.8: Four years average spare parts & outsourced maintenances work cost of ETSC

Item Type	Amount	Average	Cumulative	% individual	% Cumulative
Bearing	2,259,487.89	678,524.89	678,524.89	19.9%	19.9%
Outsourcing works	1,708,746.83	513,137.19	1,191,662.08	15.0%	34.9%
Contactors, breakers, relays	1,693,593.98	508,586.78	1,700,248.86	14.9%	49.8%
Pipes and fittings	1,601,611.60	480,964.44	2,181,213.30	14.1%	63.8%
Sheet metals and angle iron	1,010,402.10	303,424.05	2,484,637.36	8.9%	72.7%
Round bar of bronze and c. iron	734,539.00	220,582.28	2,705,219.64	6.5%	79.2%
Electrodes	643,860.32	193,351.45	2,898,571.09	5.7%	84.8%
Copper wire	402,987.82	121,017.36	3,019,588.45	3.5%	88.4%
Electrical cable and wires	394,414.46	118,442.78	3,138,031.23	3.5%	91.8%
Belts and seals	213,603.58	64,145.22	3,202,176.45	1.9%	93.7%
Hoses	206,767.39	62,092.31	3,264,268.76	1.8%	95.5%
chains	198,870.00	59,720.72	3,323,989.48	1.7%	97.3%
Bolt and nuts	161,608.90	48,531.20	3,372,520.68	1.4%	98.7%
Grinding tools and disks	91,625.40	27,515.14	3,400,035.82	0.8%	99.5%
Volkanizer kit	56,841.51	17,069.52	3,417,105.34	0.5%	100.0%

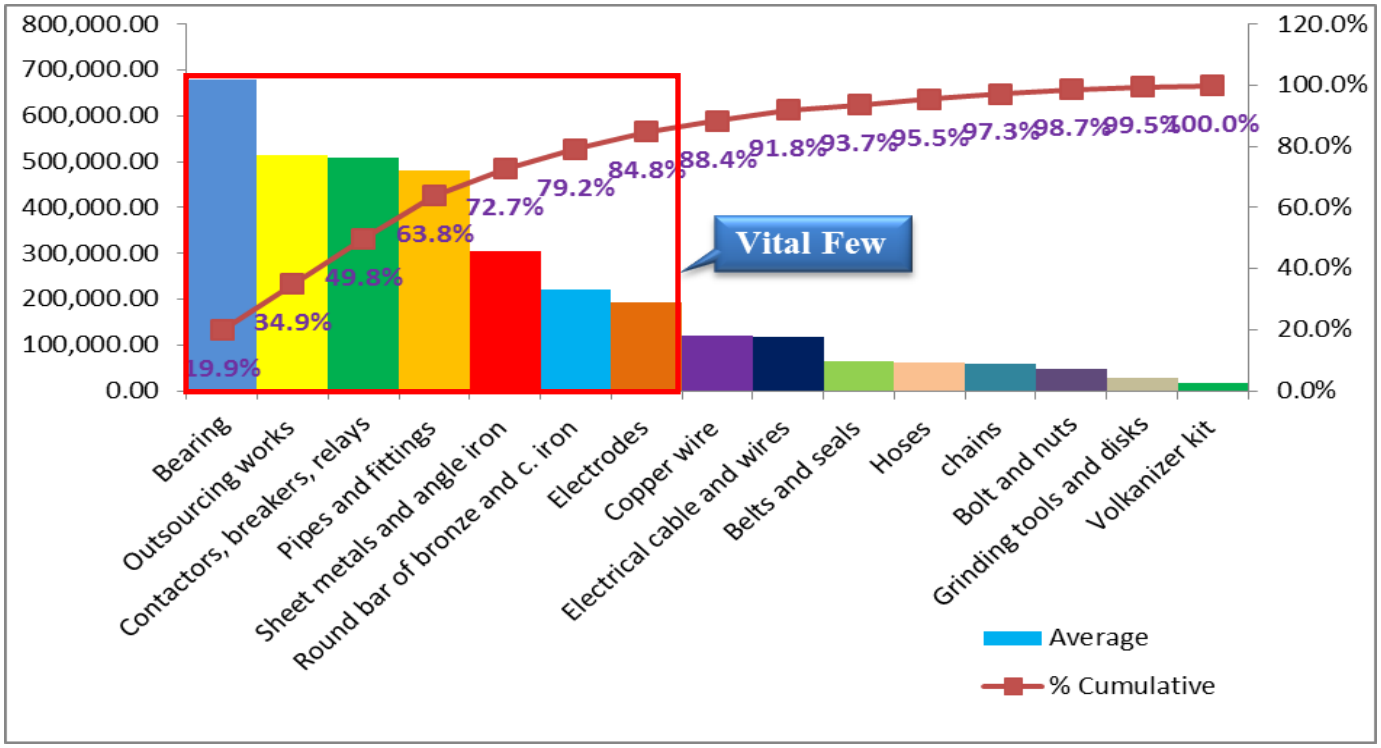


Figure 4.10: Pareto chart of four years average spare parts & outsourced maintenances work cost of ETSC

Table 4.9: Selected Xs to investigate

Xs	Description
X_1	Bearing
X_2	Outsourcing maintenance works
X_3	Contactors, breakers, relays
X_4	Pipes and fittings
X_5	Sheet metals and angle iron
X_6	Round bar of bronze and cast iron
X_7	Electrodes

Based on the information collected in the process of identifying all the process steps and creating a process map, a Pareto charts and pie charts were developed to identify major cost area, critical and frequently failure machines.

Here we are identified the major causes of increasing the cost of those factors through discussion with a technical team of ETSC to prepare an ISHIKAWA Diagram (Cause and Effect Diagram).

To draw the cause and effect diagram for the various factors that increase the maintenance cost focus group discussion approach was used. There are five professional and experienced people from the case company and the researcher involved for the causal analysis of increasing the cost of identified factors. The participant are selected from the electrical maintenance, mechanicals and finance department 2, 2 and 1 peoples from each department respectively.

As we can see from the Pareto diagram figure 4.10 about 20% of the annual costs of spare parts are caused by bearing.

I. Causal Analysis of Increasing Bearing Cost

Precision ball bearings are designed to have a long and useful life. Assuming the application is correct to begin with, maximizing longevity means bearings must be properly installed lubricated and maintained. Poor operating environments, moist or contaminated areas, and improper handling practice invite untimely bearing failure.

The possible causes of bearings failure in the case company were discussed below in the cause and effect diagram figure 4.11.

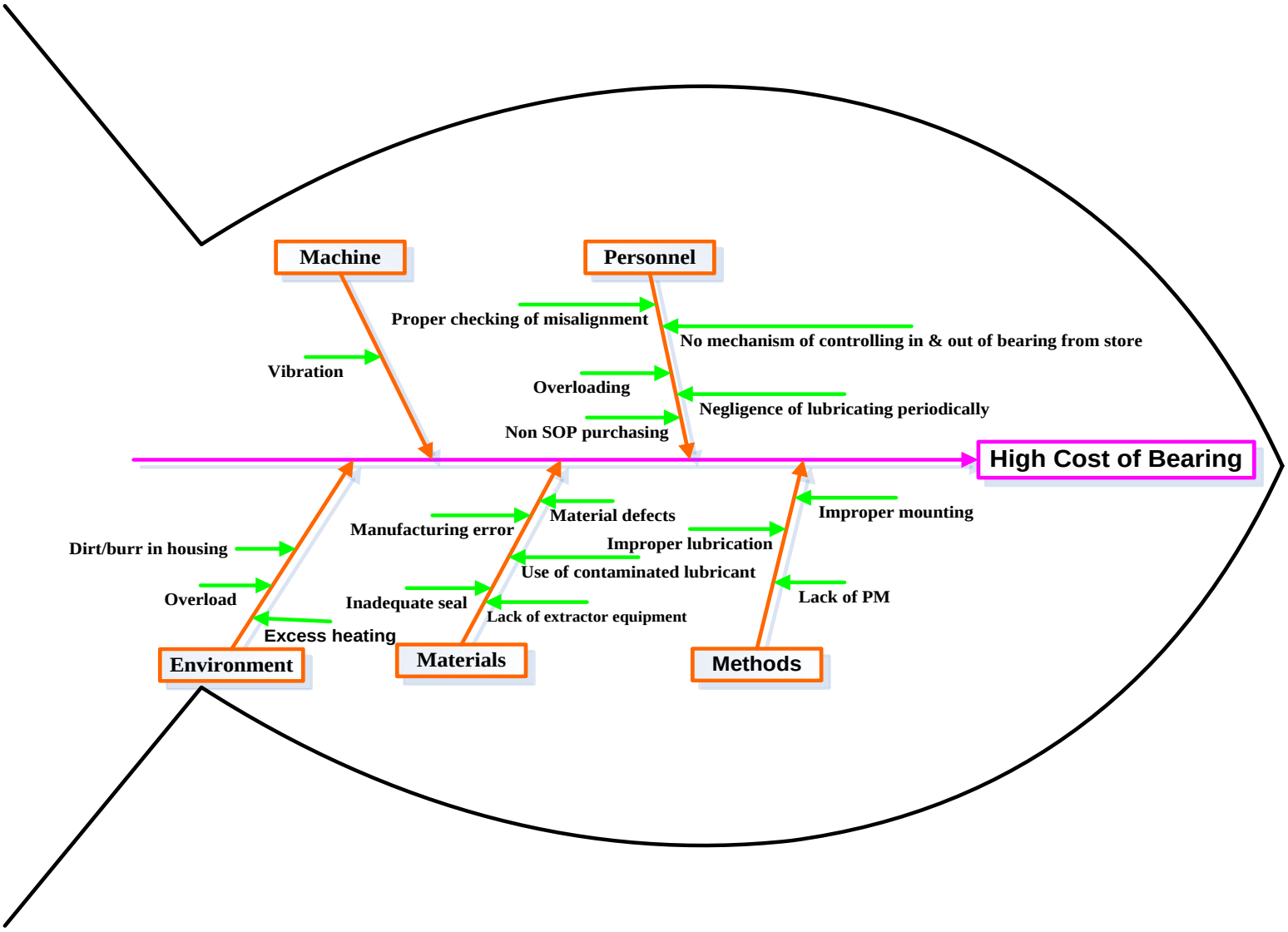


Figure 4.11: Fish bone diagram of increasing bearing cost

II. Causal Analysis of Increasing Outsourcing Maintenance work Cost

Out sourcing is a contractual agreement between the customer and one or more supplier to provide services or processes that the customer is currently providing internally (Ahmed O.Al-Mautariri, 2015).

Broadly speaking, the reasons to outsourcing include: (Ahmed O.Al-Mautariri, 2015)

- Saving money
- The need for special expertise
- Accomplish a project faster

- Insufficient in-house resources and staff freer to focus on core business

During outsourcing considering the benefit of outsourcing relative to insourcing is a good way to a firm to get the above benefits. Outsourcing thus involves a "make or buy" decision by the firms.

The various factors that increase the cost of outsourcing maintenance work for the case company are discussed below in the cause and effect diagram figure 4.12.

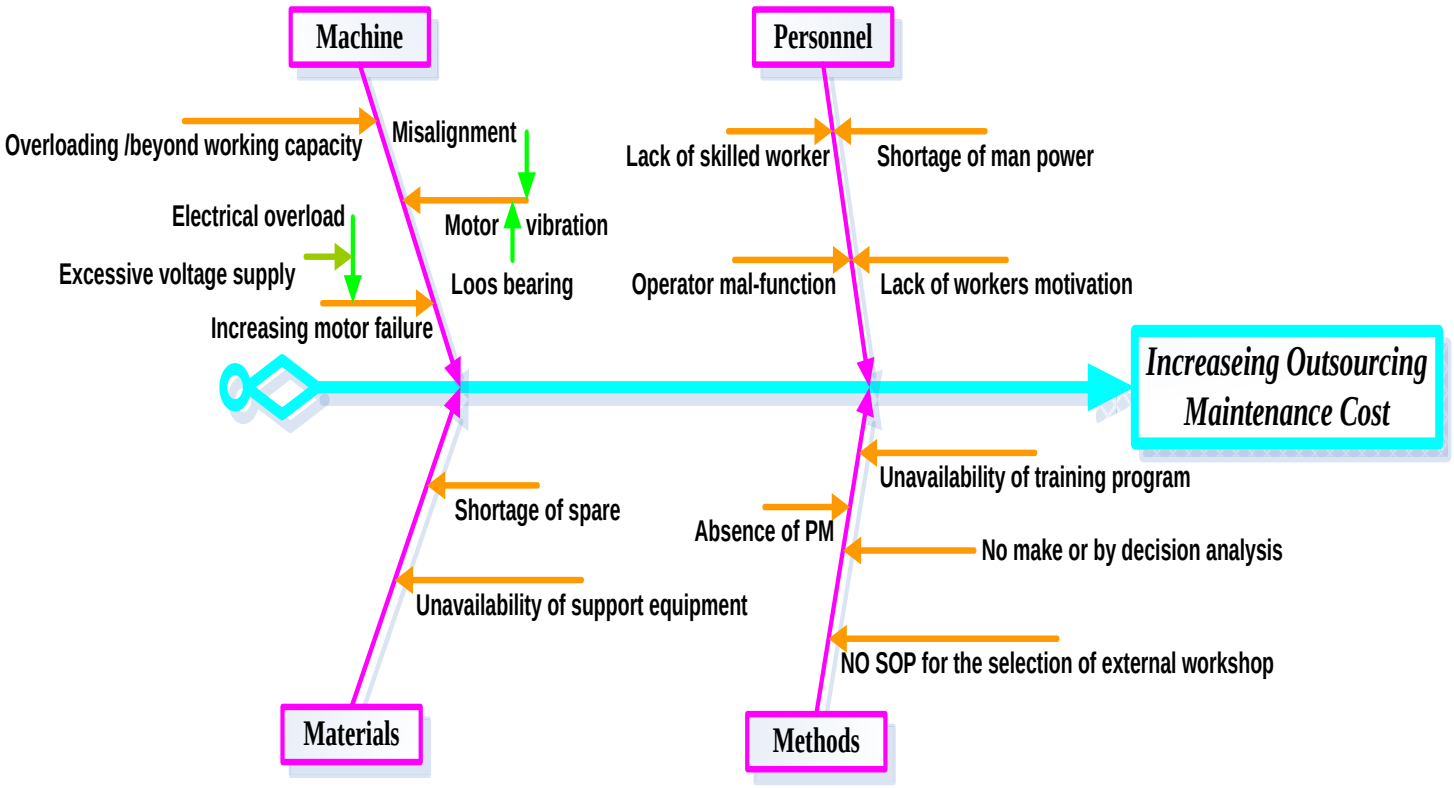


Figure 4.12: Fish bone diagram for increasing cost of outsourcing maintenance work

III. Causal Analysis of Increasing Cost of Sheet Metal, Angle Iron and Electrode

In the case company sheet metals, angle irons, U-channels and electrodes were used for various activities. The company used 75 – 85 % of the material for the preparation of manhole cover and cage for the removal of waste materials. The detail causal analyses of increasing the costs of those materials were discussed in cause and effect diagram shown below in figure 4.13.

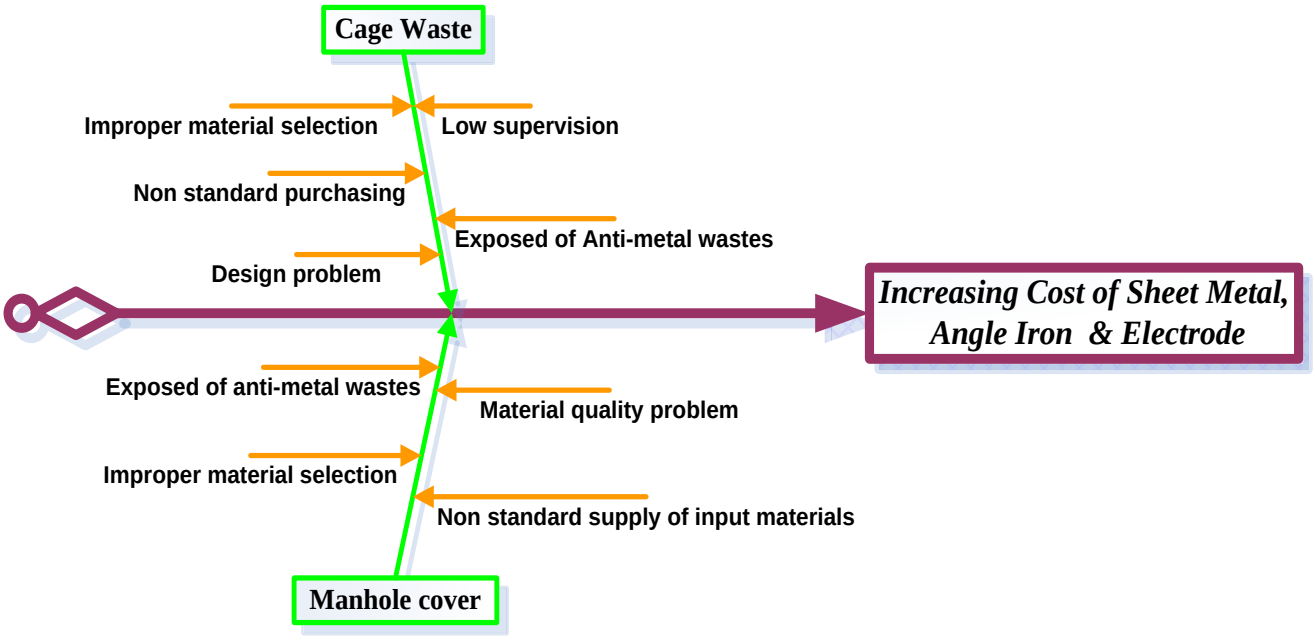


Figure 4.13: Fish bone diagram for increasing cost of sheet metal, angle iron & electrode

IV. Causal analysis of increasing cost of contactor, breaker and relay

The reasons for increasing the cost are failure of those item and the causes of failure of the components are discussed below in figure 4.14.

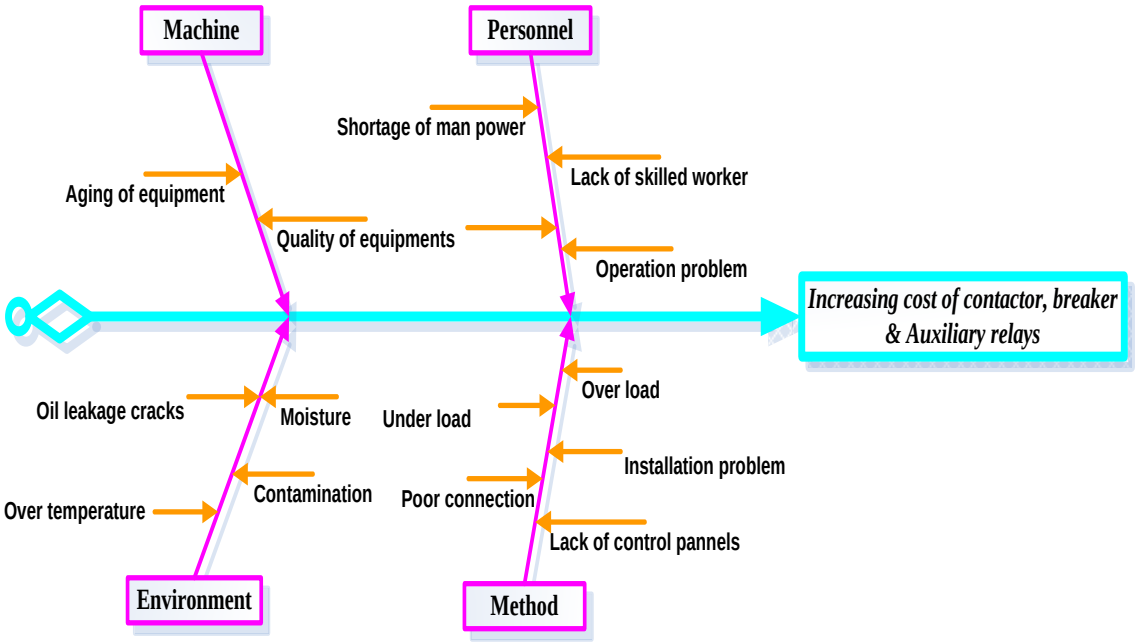


Figure 4.14: Fish bone diagram for increasing cost of contactor, breaker and relay

4.4.2. Critical and Frequently Failure Machines

As already discussed in the literature parts there are various methods to classify equipment criticality. For example according to Börjesson and Svensson determination of the equipment criticality should be based on the cost of past events (Gustav fredriksson & Hanna Larsson, 2012). To achieve the objective of this study Always Better Control (ABC) equipment classification method were used for classification of equipment in order to assess the need of maintenance and to optimize the maintenance activities. The classification is made with regard to six factors (Gustav fredriksson & Hanna Larsson, 2012):

1. Safety risk associated with breakdowns – **S**
2. Quality problems, customer complaints or scrap – **Q**
3. The extent of time during which the equipment are used for production – **T**
4. Obstacles that arise in the production process, which affect the lead time, due to the equipment breakdown - **O**
5. Failure frequency – **F and**
6. Mean Time To Repair (MTTR) - **M**

Through the use of rules of classifying equipment and their classification process discussed in the literature parts figure 2.5 & table 4.5 the classification process are shown below in the table 4.10.

According to Figure 4.5 in the literature part a preventive maintenance program developed for equipment classified as ‘A’ or ‘B’. For equipment classified as ‘C’ is no effort made to prevent failures, those failures are allowed to occur and then repaired, i.e. a corrective maintenance program (Gustav fredriksson & Hanna Larsson, 2012).

Table 4.10: ABC classification of equipment

S.NO	Machineries List	Identification of Critical & Frequently Failure Machine using ABC Equipment Criticality Classification Factors																	Score
		S			Q			T			O			F			M			
		High risk	Low risk	Ins. risk	High risk	Low risk	Ins. risk	24hrs /day	8 to 24hrs/ day	8hrs /day	Stop whole Process	Don't cause losses	Don't stop process	F>1/2 month	1F/2 month	F<1/ 6month	MTTR >2hrs	0.5< MTTR <2hrs	MTTR < O.5hrs	
		X	○	△	X	○	△	X	○	△	X	○	△	X	○	△	X	○	△	
1	Overhead crane	X			X		△	X				○	△	X				○		A
2	Retanning drum	X			X			X			X				○		X			A
3	Fleshing machine			△		○				△			△	X			X			B
4	Vacuum drier			△	X			X					△			△			△	A
5	Summing machine	X			X					△	X		△			△	X			A
6	Shaving machine			△		○		X					△	X				○		A
7	Measuring machine			△			△		○				△	X				○		C
8	Spray machine		○			○				△			△	X		△			△	C
9	Splitting machine			△			△			△			△		○	△		○		C
10	slow comb Staking			△			△			△			△			△			△	C
11	Buffing machine			△		○				△			△			△			△	C
12	Sum set machine			△			△						△			△			△	C
13	Sinkro stocking	X				○					X		△			△			△	A
14	Ironing		○			○		X					△	X				○		C
15	paddle machine			△			△			△			△		○			○		C
16	Boiler	X			X			X			X				○		X			A
17	Compressor	X			X			X			X				○				△	**A**
18	Generator	X			X					△	X			X					△	**A**

Table 4.11: summary results of ABC classification of equipment

List of Machineries failed under Category A	List of Machineries failed under category B	List of Machineries failed under category C
Overhead crane	Fleshing machine	Spray machine
Retuning drum		Splitting machine
Summing machine		Measuring machine
Shaving machine		Slow comb machine
Vacuum drier		Buffing machine
Sincro staking		Sum set machine
Boiler		Ironing
Compressor		Paddle machine
Generator		

4.4.3. Identified Causes of Machine Breakdown

The above spare parts and outsourced maintenance cost analysis shows that increasing the cost of those factors are associated with machineries breakdown. Breakdowns are the root causes of all problems, because when they occur, machineries stop, production stops, deliveries are delayed, requires spare parts, need expertise and production defects are created; in other word a single breakdown can affect the whole processes. To avoid such critical problems adopting a preventive maintenance system is vital of any maintenance operation.

It is the universal truth that damaged equipment signaled its abnormality through unusual vibrations, noises or other symptom. If the workers had read these signs and responded accordingly, the breakdown could have been avoided. Thus the human factor is the root cause of the breakdown. So the equipment operators in case company need to be trained how to discover abnormalities so they can identify abnormalities early on. In addition to this, the overall maintenances personnel's skill to identify the rout causes of machine breakdown should be studied in order to get the causes of breakdown. The main causes of machine breakdown are listed below.

I. Non-involvement of Operators

The operators in the case company are not involved in to do any maintenance activity regarding the machines they are working. Because of this they do not consider breakdowns as their own problems. They frequently make error because they do not know and train about the following simple preventive maintenance activity:

- Breakdown caused bay operator mal-function
- How to perform regular equipment checks.

- Timing and amount of oil to use for equipment that must be oiled.
- How to replace equipment parts.

II. Lack of Preventive Maintenance

The maintenance department has not classified the critical equipment and frequently breakdown machine and they don't have preventive maintenance program. To reduce breakdown preventive maintenance is a key but the company has not clear maintenance strategy. This causes loss of productions, equipment components and increases the cost spare parts.

III. Overrunning Machine

Constantly pushing machines to run maximum performance can strain joints and cause equipment to die prematurely. In the case company the machineries work for long time and beyond their capacity or overloading which cause damage of electrical motors, bearings, failure of motor rewinding etc

IV. Untrained Operator and Technician

The company chooses outsourcing of skilled required maintenance works that may not be training the machine operator as well as the technician. Lack of training can result in abused machinery and costly breakdown. Preparing educational and training program to the maintenance craft and operator regarding how they diagnose root causes, use of preventive maintenance, and use of machinery manual to make accurate maintenance.

V. Poor Quality of Spare Parts

The quality of material is another issue for causes of machine breakdown. This is due to unclear or nonstandard purchasing process of spare parts.

4.5. Improvement Phase

4.5.1. Lean Maintenance Strategy to Reduce Maintenance Cost

In the Analyze phase there was identified various factors that increase the maintenance cost of the case company and formulate the causal analysis using fish bone diagram, the critical and frequently failures machine using ABC classification, causes of machine breakdowns and availability of management strategy in the purchasing, maintenance and finance department for the reduction of maintenance cost.

Therefore, counter actions were necessary in order to remove or minimize the factors that contribute the increase in overall maintenance cost of the company. At the further stage of analysis, improvement actions for all the important problems were proposed. For the improvement phase of this project lean maintenance strategy or principle are proposed depending on the problem that needs improvement.

Lean maintenance brings together a series of strategy and tools whose objective is to reduce wastes (Muda in Japanese). Some examples of such lean tools are: visual management systems (VMS), the 5S method (sort, streamline, shine, standardize and sustain), Value Stream Mapping (VSM) and proactive, planned and scheduled, empowered (self-directed) action teams, autonomous maintenance, computer managed maintenance system, parts and materials on a just-in-time basis and Total Productive Maintenance (TPM) (Mulugeta, 2009 & Orlando, Andrea & Paulo 2017). Through the application of such tools, organizations can achieve important objectives regarding cost reduction, personnel involvement and strategic alignment.

Some of the short comings detected by the organization's diagnosis, such as the lack of maintenance strategy, keeping historical record of equipment breakdown and downtime, differentiating critical equipment's, identifying root causes of machine breakdown, SOP in purchasing, SOP in hearing external workshop, maintenance cost reduction strategy, profitable supplier selection method and financial management system.

The following lean maintenance strategies were proposed to reduce the maintenance cost of the company in the facility mentioned.

I. Standardized Work Flow and Just in Time

Standardized work is the well-organized method in Lean principle for producing the best in class quality product. Standardized work is essential to have in all repeated and critical processes. Supply of equipment, spare parts, maintenance of machinery, and out sourcing of the maintenance works in the company are a repeated and critical process. As we discussed above in the analysis phase there are various factor that increase spare parts and outsourcing maintenance cost of Ethiopia Tannery Share Company. Among from those factors are nonstandard supplies of equipment, spare parts and outsourcing of the maintenance work. Standardization of the process is vital to make the process clears, simple and cost effective. To make standardized the supply or purchasing process of spare parts identifying the various spare part types and level of consumption is very important.

In this study from four years data identified that bearing, contactor, breaker, auxiliary relay (electrical materials), pipe and fitting, angle iron, sheet metal, electrode, round bar of bronze, cast iron and brass are the main cost center spare parts purchased by the company frequently and it account 69.8% of the total cost.

So standardized work flow and JIT in the supply or purchase of spare parts especially those critical spare parts are necessary to save the cost incurred due to nonstandard purchasing process and spare part replacement and management process in store. Also to build a JIT supply process identifying the frequently required spare part list and supplier of those spare parts are essential.

Table 4.12: Proposed standardized work flow and JIT

Gaps identified in the current purchasing process	Proposed standardized work flow and JIT
1. Lack of demand visibility ▪ The maintenance department not provide list of spare part required ▪ No spare part and supplier manual	The maintenance department must provide their demand required that is required spare part list. Based on the available list of spare part prepare spare part manuals and the corresponding supplier (importer)
2. In the selection of supplier: ▪ Involvement of purchaser only ▪ Time consuming	For the selection of supplier not controlled by purchaser. The supplier must directly relate to the company through building team from selected personnel's departments. The

▪ Problem of identifying right supplier (importer or distributors) ▪ The company have no relationship with the supplier and the supplier are not willing to deliver as a just in time requirement of spare but the company have a legal relationship with the supplier the supplier are willing to deliver the required spare parts before payment settlement that is in JIT basis.	departments are: maintenance, finance administration and procurements. Once selected the right supplier: Implement an E-Procurement System. This will streamline the procurement processes; note to mention that when it catalogues the items the organization buys in the e-procurement system, the end user will not be able to buy from any unauthorized suppliers. Once identified the right supplier make a negotiation on price quality and deliver. Based on this agreement the company not holds costly spare parts in stock rather implement JIT spare part supply and this cut holding and tide up cost.
3. Document and payment approval ▪ It is time consuming and ▪ Dual process -Time for document approval -Payment approval	To save time and decrease of machine breakdown time: 1. Cut the time spent for approval by: • By merging both the document & payment approval at a single time. • Approve either document or the payment
4. Payment settlement and receiving goods ▪ it is dual process -purchaser go for payment -purchaser go for loading goods ▪ increase transportation cost ▪ Time consuming	There is triple motion for the purchase of spare parts or other auxiliary goods. Through the use of E-procurement the time and transportation cost for collecting PI, payment settlement and loading of the goods are take place at a time. Procedure: ▪ Collect PI by email ▪ Prepare payment and inform to the supplier to make ready required spare parts. ▪ Pay and deliver the spare to purchaser warehouse ▪ Can reduce 75% of transport cost

II. Material Control

Spare parts Management plays an important role in achieving the desired plant availability at an optimum cost. The objective of spare parts management is to ensure the availability of spares for maintenance and repairs of the plant and machinery as and when required at an optimum cost. Also, the spares should be of right quality.

Every organization should proceed systematically and establish an effective spare parts management system. For the successful spare parts management, it is essential to analyze the spare parts inventory based on various characteristics such as the frequency of issues, the annual consumption value, the criticality, the lead time and the unit price.

To control spare parts used for the intended purpose the spare part store should make a controlling system during in and out of spare parts. In the case company the maintenance department asks spare parts from the spare part store and the store give the requested spare parts without asking the failed materials.

In the company there is a probability to lose spare parts by the worker specially bearing. To control such kind of lose when spare part request from maintenance crafts the store should receive the part that failed. For example if maintenance person request new bearing to maintain the machine.

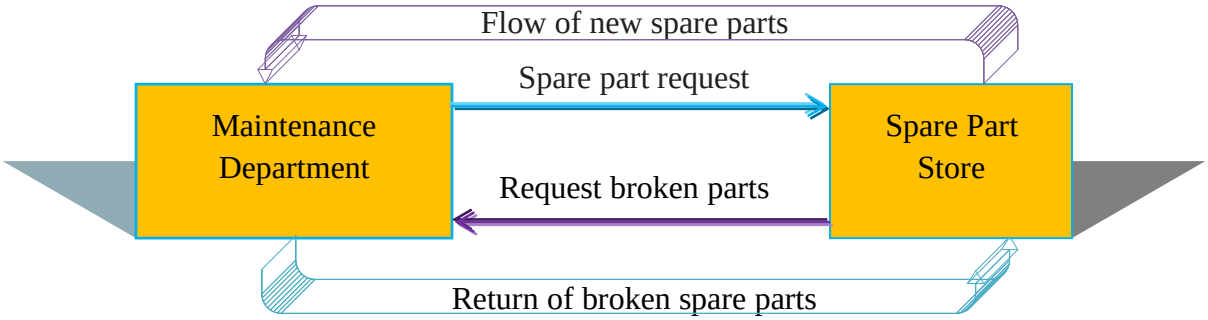


Figure 4.16: Proposed spare parts in and out controlling system

The other ways of controlling and reducing the material costs are through the use of appropriate material for the variety of application. In the analysis phase identified the factors that increase the cost of angle iron, sheet metal, and electrodes. The main factors are the preparation of manhole cover and cages (waste removal basket). The cost of this material is increase due to problem on the selection of the right materials. Through changing the material type for the preparation of metallic manhole cover to concrete manhole cover the company gain per three

year a benefit of more than 400,000. The material cost analysis of metallic manhole cover and proposed concrete manhole cover were shown below in the table 4.13 and 4.14 respectively.

1. Manhole cover

A manhole cover is a removable plate forming the lid over the opening of a manhole, to prevent anyone or anything from falling in, and to keep out unauthorized persons and material.

In the case company inside around 60 manholes available currently this manholes made from sheet metal and angle iron. Due to expose of various chemical, other mechanical impacts the manhole covers are short service life and maximum 4 to 6 months.

The material costs of manhole cover for the Ethiopia Tannery Share Company are shown below in table 4.13.

Figure 4.17: Metallic manhole cover used in the case company

Table 4.13: Metallic manhole cover cost calculation

No.	Material	Dimension	Units	Quantity	Unit Price (Birr)	Total Price (Birr)
1	Sheet metal	2X1X2m	Pcs	0.25	1340	335
2	Angle Iron	6X60X6000mm	Pcs	0.5	1880	940
3	Electrode	ϕ3.25mm	Pkt	0.1	500	50
Total cost for a single manhole cover						1325
Grand total for 60 manholes cover						79,500
For one year						159,000

But through the use of other alternative materials the company reduces the total cost of manhole cover like use of concrete manholes cover, wood made covers and fiber materials. The company save not only their money but also improve the safety, durability, reduce maintenance work, man power requirement and material consumption. The cost analyses of the concrete manhole covers are shown below in table 4.14.

Table 4.14: Concrete manhole cover cost calculation

No.	Material	Measurement	Unit Price (Birr)	No. of Material required	Total Price (Birr)
1	Cement	Quintal	240	0.25	60
2	Reinforcement bar 10mm	Berga	440	0.5	220
3	Mold preparation wood	M^2	80	0.8	64
4	Aggregate 2mm	M^3	420.833	0.025	10.52
5	Sand	M^3	464.10	0.02	9.282
6	Black wire	Kg	80	0.1	8
Total cost for a single manhole cover					372
Grand total for 60 manholes cover					22,320
For > three years					22,320

Figure 4.18: Concrete and wood manhole cover sample image

2. Cage (immersed waste receiver basket)

This cage immersed with various chemical bases due to this the material of the cage that is sheet metal, angle iron, u-channels and round bar cast irons are burned and damaged because the material react with the chemical and this causes short service life about 3 to 4 months. The material costs of cage are shown below in table 4.15.

Table 4.15: Cage materials cost calculation

No.	Material	Dimension	Units	Unit Price (Birr)	No. of Material required	Total Price (Birr)
1	Sheet metal	2X1X2m	Pcs	1340	4	5360
2	Angle Iron	6X60X6000mm	Pcs	1880	2	3760
3	U-channel	10mm	Pcs	4500	1	4500
4	Round bar steel	¢30mm	Pcs	1550	1	1550
5	Electrode	ϕ3.25mm	Pkt	500	1	500
Total cost for a single cage						15,670
Grand total for 8 cage						125,360
For one year						376,080

Through similar fashion as the manhole cover the company can gain cost benefits through the use of timber land wood, Teflon materials, design change and by painting the existing cage using non-reactive paints with the chemicals etc.

III. Autonomous Maintenance and Training

- ✓ **Operator Maintenance**

Good maintenance management requires operators to understand their equipment. The job related expertise must not be limited to simply operating the equipment; it must also include a lot of things traditionally regarded as maintenance work. All of the equipment operators need to learn how to detect abnormalities. This means acquiring the ability to look at the quality of the product and the performance of the equipment and notice when something is strange. This depends on the following three skills.

- A clear understanding of criteria for judging normal and abnormal conditions (the ability to establish equipment condition)
- Strict enforcement of condition management rules (the ability to maintain equipment condition)
- A quick response to abnormalities (the ability to repair and restore equipment condition)

When an operator has mastered all three skills, he or she will understand the equipment well enough to recognize the causes of future problems and realize weather the machine is in good condition or not. The following points explain some of the skills that operators should have.

The ability to detect equipment abnormalities and make improvement

- Ability to watch for and discover abnormalities in equipment operation and components.
- Understanding the importance of proper lubrication, including correct lubrication methods and methods for checking lubrication.
- Understanding the importance of cleaning (inspection and proper cleaning methods)
- Understanding the importance of coolant

In order for the maintenance department to focus on extensive problems and to develop their knowledge for maintaining and repairing equipment operator maintenance is a vital part. The higher the operators knowledge is, and the greater competence he/she have, less the maintenance have to deal with these minor tasks which only are time consuming. Thus, the complexity of equipment and the operators' skills are factors which may decide the extent of operator maintenance (Wireman, T. 2010).

This area address issues such as:

- The percent of the total amount of operations personnel that generate work order requests.
- The tasks which the operators are trained to perform.

✓ **Training**

Training is the key to greater knowledge and improved performance. Training of personnel is an extremely important component of the managed maintenance programmed. Training can be used in a variety of ways, including:

- Orienting and informing employees,
- Developing desired skills,
- Preventing accidents through safety training,
- Supplying professional and technical education, and etc

IV. Computer Maintenance Management System (CMMS)

Like its name suggests, Lean Manufacturing eliminates waste – and a CMMS can help with just that. By looking for trouble areas that arise in maintenance, workforce scheduling, inventory, work order management and preventive maintenance, a CMMS can help the company to focus on the tasks that matter and trim the fat that can slow the company down.

When using a CMMS, tasks such as preventive maintenance becomes more efficient and equipment uptime increases. The right plat form will give you the power to make better decisions when it comes to your budget, as well, including:

- Trends in over maintaining become easy to spot
- Workforce scheduling seen at a glance with a calendar view
- Spare parts inventory management so you know you have the right parts on hand at the right time and stored in the proper places.
- To develop trucking of the rout causes through recording history of equipment like;
    - Causes of breakdown
    - Action taken
    - Results of action etc
- To make planning and scheduling of maintenance activity weekly, monthly, quarterly and yearly.

Additionally, CMMS ensure that work orders are filed in a central system, allowing all technicians access from any desktop or mobile device. This mobility means less time looking for work orders, more accurate data, and increased organization.

V. Preventive Maintenance (PM)

This concept is a type of physical checkup of the equipment to prevent equipment breakdown. Preventive maintenance includes activities which are started after a period of time or amount of machine uses.

This type of maintenance depends on the estimated probability that the equipment will break down in the specified interval.

The preventive works are as follows:

- Inspection
- Equipment lubrication,
- Cleaning,
- Parts replacement,
- Tightening,
- Adjustment
- Lubrication

To determine the frequency of the inspection, in in the case company, the following engineering analysis should be considered

- The age of the machine, its condition and value
- Severity and intensity of service
- Hours of utilization, are they prolonged or intermittent
- Susceptibility to wear and tear – is the machine subjected to dirt, friction, fatigue, stress and corrosion?
- Susceptibility to damage – is the machine subjected to severe vibration, overloading abuse, heat and freezing cold?
- Susceptibility to losing adjustment during use – will the maladjustment or non-alignment affect the accuracy or functioning?
- Will the lack of proper balancing affect performance?
- Safety requirements and considerations

Through implementing the lean tools and principle discussed above the company will reduce the factors increasing maintenance cost, reduce machine breakdown and improve the overall maintenance process of the company.

4.5.2. Proposed Model Development for Maintenance Cost Reduction

Based on the findings in this master thesis, a Customer Based Model (CBM) was developed for the reduction of maintenance cost of Ethiopia Tannery Share Company.

The model was named customer based because it is based on the customers, both the internal customers; the maintenance crafts men and technicians, purchaser, and the external customers finance.

The customers' needs and expectations are identified and then translated into maintenance objectives which then were used as a foundation to model development.

Through incorporating the lean maintenance cost reduction strategy such as standardized work flow and just in time, material control, autonomous maintenance and training, computer maintenance management system, and preventive maintenance discussed above and other elements.

In this paper proposed a maintenance cost reduction model to reduce the overall maintenance cost of Ethiopia Tannery Share Company.

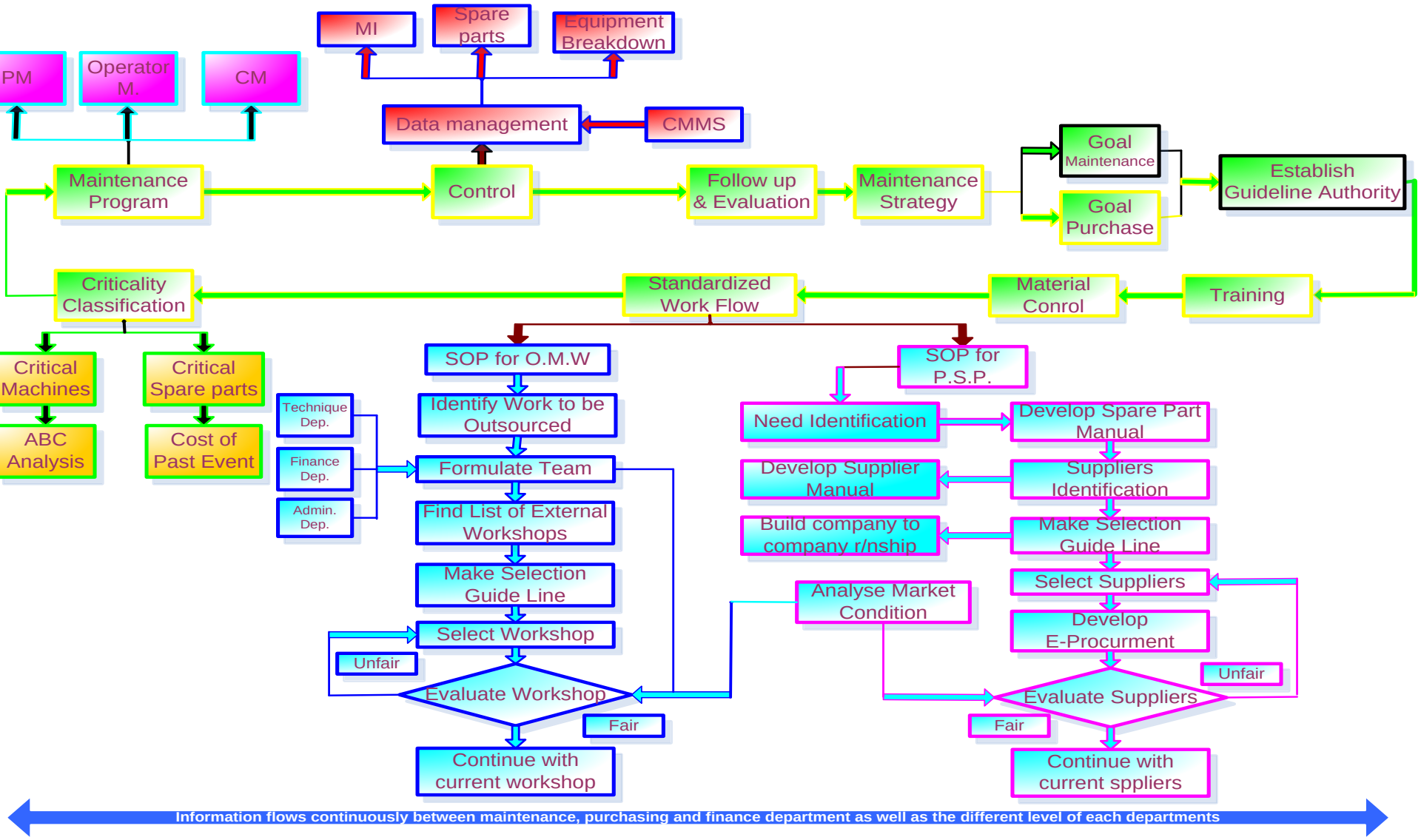


Figure 4.19: Proposed maintenance Model for Ethiopian Tannery Share Company

4.5.6.1. Description of the Component Parts of the Model

The following describes each part further. It discusses the content of what the authors believe are of interest in various stages and levels of the model.

Goals purchasing and Goals maintenance

As shown in Figure 27 it is recommended by the authors that the goals for the purchasing and maintenance department are to be developed alongside one another. The importance to understand how the plant operates, the relationship between the plant and its market and how maintenance function within this context the purchasing and maintenance departments are should work together to reduce the maintenance cost and they are inseparable from each other. Furthermore, the maintenance and purchasing departmentsare to be considered as partner within the business with shared overall goal and all functions within the business contribute to profitability.

Establish and document authorities

The leader describes to all the employees moving in the same direction, thus, the leader must be able to articulate the vision and set goals that are realistic and acceptable.

It has been argued that there exists a consensus among executives that a substantial degree of allocation is a prerequisite for enable the leader to work with these kinds of matters and not being tied by routine matters. For this reasons, it is, in the authors believe, important that the leader is focusing on the overall goals and objectives, while delegating responsibility for daily routine matters. Thus enabling the leader the opportunity to manage strategies, economic issues and thinking in terms of customer and market perspective. If this is to be performed, focusing on continuous improvement will be facilitated and become natural. However, delegating should only be executed if the subordinate are willing to accept the responsibility, hence fore, the delegation should also be well documented and leaving no misinterpretations or ambiguities.

Criticality Analysis

Perform a criticality analysis in order to establish which equipment and spare parts that are critical and thus, should be assigned the resources. When the financial planning cost of past event and root causes analyses are performed the critical analysis result is used as an aid to know where to assign the resources. Also to establish maintenance program the criticality analysis result has great help

.

- **Critical Equipment and Spare parts**

When performing the criticality classification of equipment's and spare parts recommended to follow the ABC classification and cost of past event described in the literature parts. This is, in order to assess the need of maintenance and to optimize the maintenance activities.

Standardize work flow

Methods for the root cause analyses of failures are used to facilitate and standardize the work procedure during the problem resolution and also the documentation. If this is done in the correct way failures are eliminated or reduced, which in time can save significant costs. If these procedures are standardized the problem-solving and problem-finding procedures can continuously be improved and the work will be more efficient and less time consuming. It also ensures that a sufficient amount of data and information are documented from each analysis for future work, follow-up and as a ground for investment arguments.

Maintenance program

The maintenance program needs to be established in order to secure equipment availability and by that satisfy the external customer. The program which is established should be improved continuously, due to for example, occurring events and capacity changes. Root cause analyses should continuously be performed, which also may initiate to maintenance program improvements.

The maintenance program should be evaluated according to any of the following concepts in order to categorize the tasks and decide the approach:

- **Operator Maintenance**

Operator maintenance means that maintenance tasks are carried out by the operator, tasks such as lubrication, cleaning and minor repairs may be carried out by the operator. It is suggested that Ethiopia Tannery Share Company develop an operator maintenance program. The maintenance activity done by operator should be documentedand it should also include signature by the one performing the maintenance task. This is, to provide the maintenance craftsmen and technicians with the ability to communicate and discuss with the responsible operator about the maintenance performed, if necessary.

- **Preventive Maintenance – PM**

This approach to maintenance management is predominantly recurring or time-driven tasks performed to maintain acceptable levels of availability and reliability. By actively work with preventive maintenance, the downtime can be minimized, and therefore the productivity is maximized. The PM program is the key when improving the maintenance process. The amount of reactive maintenance is reduced by this program. It is therefore major importance to insure good coverage of the equipment in the program.

- **Corrective Maintenance – CM**

Preventive maintenance not always the best approach to choose. This is valid for equipment whose failure pattern does not depend on age and thus, do not have an identifiable wear-out age and also is non- critical (established from criticality classification) a corrective maintenance, i.e. run-to-failure, program may be to prefer.

Control

Increased control of the maintenance organization may provide a reduction of costs.

- **Data Management**

In order to control the maintenance activity proper information about events that occur needed. Data is the foundation to gain control and without effective data gathering cannot incidents be truly investigated, root causes cannot be solved, improvements is hard to perform and the optimal amount of spare parts is difficult to establish (Gustav fredriksson & Hanna Larsson, 2012).

- **CMMS**

In order to control and manage maintenance tasks effectively a computerized maintenance management system is needed (Gustav fredriksson & Hanna Larsson, 2012). Therefore, it is recommended to use a computerized maintenance management system which also presents data visual and is easy to use. That is, to facilitate the control of the maintenance activity and to ease the maintenance craftsmen's reporting efforts.

- **Spare Parts**

Keep the critical spare parts available in storage to avoid unnecessary waiting time and costs due to for example transportation and ordering when it is needed. It is recommended that the maintenance department themselves control the inventory of spare parts with regard to criticality.

- **Maintenance Improvement**

Maintenance should improve continuously, in order to create motivation among employees assign appropriate persons to lead improvements. It is crucial that management support and inspire to improvement efforts and also creates conditions to cooperation when working with improvements.

Follow-up of goals achievement

It is difficult to control and improve what is not measured and followed-up (Gustav fredriksson & Hanna Larsson, 2012). The achievements of goals need to be followed up, the work performed need to be evaluated and if suitable should established methods and activities be corrected. After correction should results be followed-up again, first when results are satisfactorily the team moves on to the next step.

Maintenance Strategy

At this point are a strong foundation of data, results, methods and activities available in order for the organization to formulate the maintenance strategy. Together with internal and external customers; establish standards for how to work, which problem solving tools to use and how to document data. When the strategy is formulated it should be evaluated, modified and improved at sufficient intervals

4.6. Control Phase

Control phase is an essential and necessary for any performed work need continuous monitoring and improvement. It is imperative to control the maintenance activity and take measurement for maintenance procedures, equipment performance and any faced problems continually over the time, in order to find best practice, worst practice, trend and appropriate solutions that able to make continuous improvement of the maintenance process safely, fast, high-quality, inexpensive and meets the desire of customers satisfaction which requires the participation of everyone. To maintain the proposed improvement action, following activity should be performed:

- Proposed PM procedure must be standardized and documented.
- Proposed purchasing and outsourcing of the maintenance work process must be standardized and documented.
- Spare part manual that contain spare part list and supplier manual that contain list of importer and distributor must be developed.

- The proposed spare parts in and out controlling system must be followed.
- The developed model in this study should be implemented.

To control machine breakdown identifying the root causes of breakdown is one of the approach and this is achieved by collecting continuous data regarding maintenance history of the equipment.

Additionally, it needed to ensure traceability of data which means that it record dates and number of work orders related to each one defect/breakdown. This is useful contextual data providing as much information about process events as possible.

Table 17 below illustrates the check sheet to record data and each one of the machines must have its own sheet. It may be made of either in Excel or Minitab software, in order to have the data statistically processed and produce relevant reports and charts. This helps to identify the root causes of breakdown and to control the causes. To accomplish this proposed CMMS must be used.

Table 4.16: The check sheet for recording data

Work Order	Requested Date	Breakdown Time	Symptoms	Defects	Causes	Action Taken	Results	Remarks

4.7. Validation of Methods and Results

The literature described in the thesis is considered to be validated through the use of face validity, meaning that it has been examined by experts within the area; for example, through the support from the author's tutors.

For validation of the methods and results, it is considered that both parts have been validated through face validity. Because of time constraint validation of the methods and results has been done by focus group discussion in a meeting with the presence of finance and maintenance manager, mechanical division heads, electrical division heads and maintenance procurement coordinator and technical experts.

During discussion, raised points include relevance of the developed maintenance strategy model, model feasibility; challenge to implement the models and area where the model has to be improved.

As per the discussion, the proposed model is relevant and feasible because it addresses practical problems. It requires change in the existing purchasing and outsourcing procedure and need additional resource and equipment to implement CMMS. In addition to this all machine operators, maintenance and purchasing department staffs required extensive training to implement the proposed maintenance strategy model effectively and efficiently.

CHAPTER FIVE

5. CONCLUSION & RECOMMENDATION

5.1. Conclusion

The purpose of this thesis is to develop a maintenance cost reduction strategy and in order to do so have four research questions been formulated. These four questions are aimed at grasping the key objectives of the thesis and also to function as guidance along the way of developing the maintenance cost reduction strategy model. The four research questions are: what are the major factors increasing the maintenance cost and the underlying causes, how to select appropriate maintenance strategies to the critical & frequently failure machine and how to manage maintenance spare part requirement and build cost effective SOP in purchasing.

The maintenance department at Ethiopia Tannery Share Company consists mainly of a fire-fighting or reactive approach, events and failures choose the direction. This shows most of the maintenance activities are corrective action rather than preventive. This causes an increase in machineries breakdown. An increasing of machines breakdown, lack standard operation procedure in purchasing and outsourcing of the maintenance work the company cost an average of three and half million birr for spare parts and outsourcing maintenance work. Thus, this paper finds out the major factors that increase maintenance cost and ways to minimize them in order to reduce the maintenance cost.

The main factors of increasing maintenance cost investigated in the paper for case company are bearing, outsourcing maintenance work, contactor and breakers, pipe and fitting, sheet metal and angle iron, round bar of bronze and electrode and they account 19.9%, 15%, 14.9%, 14.1%, 8.9%, 6.5% and 5.7% respectively.

On the other hand the critical and causes of machine breakdown are analyzed in this paper in order to select the maintenance strategy for the machines. The main causes for machine breakdowns are non-involvement of operator, lack of preventive maintenance, overrunning of machineries, untrained operator and technician and poor quality of spare parts.

The observation, interview and questionnaires survey in this thesis are an approach for gathering information about the maintenance, purchasing and finance department. The result from the analysis shows that the company has limitation of focus on preventive maintenance strategies, record keeping and documentation on maintenance activities and history, knowledge and skill

gap on how to maintain a machine, how to use maintenance tools and techniques and over all, unavailability of all-inclusive and standardized maintenance, purchasing and financial strategy model across the aboard the case company follows.

The areas to greatest potential for improvement were identified such as education, standardization of purchasing and outsourcing procedure, financial planning, data management, CMMS, material control and preventive maintenance. In addition, the need and profitability for operator maintenance program may be determined in order to further develop the organization and the maintenance work.

Furthermore, this paper proposed a model for the maintenance strategy to reduce maintenance cost, considering the existing problem. The model simplifies the whole process and makes the activities to be efficient and standardized. So the maintenance cost will be reduced. It is developed by coordinating the seven major duties of maintenance; critical classification, maintenance program, control, follow-up and evaluation, training and standardized work flow.
Maintenance manager has a great role forthe developed model. It is the responsibility of this section to coordinate the operators, corrective and preventive maintenance and the data managementsand set the maintenance program considering the factors and the feedback of maintenance report.
Validation of the model proposed done by focus group discussion with accounting and finance manager, maintenance manager, mechanical division heads, electrical division heads, maintenance procurement coordinator and technical experts. Valid feedback given on requirement of additional resource and training to operators, purchasing and maintenance staff and based on the feedback model does not amended. The author believes that the company is beneficial of implementing proposed model even if it requested additional resources.

5.2. Recommendation

Based on the result of the study the following recommendation are proposed for the case company in order to reduce maintenance cost, to identify root causes of machine breakdownand improve the existing purchasing, finance and maintenance procedure.

- Training is the key to greater knowledge and improved performance. Training of operators and technicians is an extremely important component of the managed maintenance programmed. So the company should have a training program.
- The company should give priority for critical equipment and spare parts at the time of performing preventive maintenance activities and purchasing of spare parts respectively.
- The company should develop CMMS for controlling of spare parts, machine breakdown, and history of equipment, maintenance report and the overall improvement of the maintenance program.
- In the improvement phase proposed spare parts in and out controlling system this is ease to implement and the company should be implement it.
- To reduce by 90% the cost of sheet metal, angle iron, u-channel, round bar and electrode for the preparation of metallic manhole cover the company should be used proposed concrete manhole cover
- First and at most the company should implement the proposed model for the improvement of the maintenance and purchasing activity of the company to reduce the maintenance cost
- To sustain the proposed improvement solution and the model developed the company recommend to implement suggested point in the control phase of the projects.

6. FUTURE RESEARCH AREA

This study focuses on Ethiopia Tannery Share Company but that it is advantageous implements to see the impact in other factories. Identifying other maintenance cost reduction methods which are not looking in this study, implementing the proposed model on other operational and automotive maintenance area of the factory.

If the researches done are not implemented they should be implemented by testing the feasibility of all the research made by so many scholars until today and setting rules how to implement the study then check the validity in practical.

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APPENDIX I: Interview Questions

The interview questions are built to understand the various maintenance costs, cause of machine breakdown and factor increasing maintenance cost and purchasing methods and relationship with maintenance department. It assigned the interview questions to maintenances and purchasing department.

- **For maintenance department**

1. Where are the most critical areas or departments needing equipment reliability? (Critical Path Machines)?
2. Would you please tell us at least 7 frequently failure machines?
3. How many hours of unscheduled downtime, from your CMMS or "work orders." How many maintenance hours by in-house or by contracted support personnel?
4. What are the major factors that increase machine breakdown?
5. What is your average "cost per hour" for equipment downtime?
6. Could you please tell us the various maintenances cost of your company/in general?
7. What are the factors that increase the maintenance cost?
8. Do you consider the technicians to have sufficient competence?
9. If you can't restore equipment, how do you proceed?
10. Do you think out sourcing maintenance work increase the past two year?
11. What are causes that increase out sourcing of the maintenance work?
12. Do you think there is a skill limitation in the maintenance craft employee?
13. How the maintenance departments work to reduce maintenance cost?
14. Do you think your department provides all the necessary information to the purchasing department?
15. How your departments support the purchasing department to reduce maintenance cost?

For purchasing department

1. How many employees work in purchasing department?
2. How the purchasing department organized?
3. What are the main activities of the purchasing department?
4. Do you have standard operation procedure in purchasing? Do you think it is cost effective?
5. Do you think the existing supplier selection methods of the company make profitable? If yes how? If no why?
6. What are the factors that increase the purchasing cost of your company?
7. If there is lack of demand visibility from the maintenance department how you categorize the spare part requirement and supplier? Could it affect the cost? How?
8. Purchasing is an important parts of maintenance cost reduction, what do you think the relationship between purchasing and maintenance cost reduction?
9. How your departments work to reduce time and cost of purchasing? (Regarding transport, spare parts and proforma collection, ordering and order receiving)

- **Note: -** For each question answer page is provided in the next page.

APPENDIX II: Questionnaire Survey

The questioners are built to understand the existing financial management methods, maintenance management, strategy, maintenance department organization and their relationships with others departments of Ethiopia tannery Share Company. And the questioners are assigned to the finance and maintenances departments.

- **For finance department**

1. Based on an annual maintenance cost report how do you classify your organization regard to categorizing the various factor that increase maintenance cost?

☐ The organization has extensive knowledge - 4pts

☐ Limited knowledge – 2pts

☐ Low or no knowledge – 0pt

2. If your organization has extensive knowledge to question number 1 what are those factor?

3. Do you have any documented financial management strategies that reduce maintenance cost?

☐ Yes – 4pts

☐ No - 0pt

4. Is there any scheduled meeting program with the maintenance, purchasing and spare part store to discuss the means to reduce maintenance cost?

☐ Yes – 4pts

☐ No - 0pt

- **For maintenance department**

Maintenance strategies

1. Is there a maintenance strategy?

   ☐ Yes – 4pts

   ☐ No - 0pt

2. Is it written or oral (if written may I have a copy?)

Organization of maintenance department

3. How the maintenance department personnel organized? (Regarding craftsmen, chain of command, section wise, machine wise etc.)

Machinery categorizations, historical data organization and failure analysis

4. Do you have a historical data of work order or machine breakdown, the corrective action taken and its result? : If your answer is yes may I have a copy

   ☐ Yes – 4pts

   ☐ No - 0pt

5. Is there any written categorization of machineries in the maintenances activity based on frequency of failure, production requirement, parts sensitivity, aging, cause of failure etc?

   ☐ Yes – 4pts

   ☐ No - 0pt

6. If yes what are the categorization? Can you list the machineries in each category?

7. What are the roots causes of frequently failure machines? What measures taken to reduce frequency of failure?

8. To what extent are failures clearly identified to its root cause? [%]

- ☐ At least 80 % to 90% of all failures – 4 pts
- ☐ From 65% to 80% of all failures – 3 pts
- ☐ From 40% to 65% of all failures – 2 pts
- ☐ Less than 40% of all failures – 0 pts

9. Is failure analysis conducted by the use of an analysis tool such as fishbone, tree, five why's or Pareto, to assure accuracy and standardization for each analysis?

- ☐ Yes – 4pts
- ☐ No - 0pt

Operator involvement and skill level of maintenance personnel

10. Involvement of operators in the maintenance of their machine and informingthemwhen breakdown occurs due to operator mal-function:

- ☐ Excellent – 4pts
- ☐ Very good – 3pts
- ☐ Good – 2pts
- ☐ Don't know – 0pt

11. Your view to let the operators perform some of the routine PM?

- ☐ Excellent – 4pts
- ☐ Very good – 3pts

- ☐ Good – 2pts
- ☐ Don't know – 0pt

12. The quality and skill level of the maintenance work force is:

- ☐ Excellent – 4pts
- ☐ Very good – 3pts
- ☐ Good – 2pts
- ☐ Don't know – 0pt

13. The quality and skill level of supervisor group is:

- ☐ Excellent – 4pts
- ☐ Very good – 3pts
- ☐ Good – 2pts
- ☐ Don't know – 0pt

Training program in maintenance

14. Providing training periodically for operators and technician regarding preventive maintenance and root cause of breakdown diagnostic:

- ☐ Excellent – 4pts
- ☐ Very good – 3pts
- ☐ Good – 2pts
- ☐ Non-existence – 0pt

Outsourcing the maintenance work

15. Can you mention some of the reason for out sourcing maintenance work in your company?

16. Do you think out sourcing maintenance work increase the cost of maintenance?

☐ Yes – 4pts

☐ No - 0pt

17. Is there any written standard procedure during outsourcing of the maintenance work in your company to find external workshop (if yes may I have a copy?)

☐ Yes – 4pts

☐ No - 0pt

18. Do you have a plan to reduce out sourcing maintenance work?(If yes how?)

☐ Yes – 4pts

☐ No - 0pt

19. As a maintenance department do you have any maintenance cost reduction strategies to follows?

20. Do you think any alternative approaches or methods that reduce maintenance cost? (Through employee wage & over time, machine, tools, materials, spare parts usage and outsourcing maintenance work)

- **Note: -** For each question answer page is provided in the next page.

APPENDIX III: Interview Guide for Proposed Model Validation

1. Does the proposed model help you formulate relevant maintenance strategies?
2. How is relevant the proposed maintenance strategy model for the reduction of maintenance and purchasing cost of the company
3. What are the challenges to implement the proposed model?
4. Are you satisfied with the factors considered to reduce maintenance cost in this project?
5. Pros and cons of implementing the proposed models in your company?

APPENDIX III: Literature Summary

Continued from table 2.6 in the literature summary

Authors & Date	Title	Objective	Methods	Finding
Alexander Börjesson 2011	Critical equipment classification and cost reduction within professional maintenance	To finding an appropriate method to determine equipment criticality in order to help the maintenance department prioritize among work orders and to increase equipment availability	semi-structured interviews, seminars and workshop	Work routines for how to perform maintenance and for how to control spare part inventory is also being suggested.
MohamadTabikh 2015	Downtime cost and Reduction analysis	To investigate on downtime costs in Swedish manufacturing companies, and how they are analyzing its reduction.	Interviews, Survey and questionnaire	The main results obtained from the investigation show that the estimated downtime cost constitutes about 23.9 % from the total manufacturing cost ratio, and 13.3 % from planned production time.
Majeed Assaf& PatrikJukic. 2015	Utilizing Lean Six Sigma to Improve Material Handling Operations in the Production of Heavy-Duty Engines	To implement DMAIC method used in the Six Sigma concept for the improvement of production processes connected with maintenance.	LSS	Led to financial contributions achieved through a more stable and capable process in the heavy-duty engines main production line. The ergonomic improvement as well as that of productivity could also lead to financial benefits for organizations in different types of industries

MichałZasadzień	Application of the six sigma method for improving maintenance processes	To address the causes of machines breakdowns by developing a maintenance management framework and thereby increase the competitiveness of the company	Six Sigma DMAIC	Identify which types of breakdowns cause the most machine stoppage. Provedthat it is possible to effectively use quality engineering methods and tools for maintenance process improvement
EyerusalemMekasha	Maintenance Management Framework Development for Competitiveness of Food and Beverage Industry	To enhance the productivity through improved maintenance systems		Identify bottleneck machines Identified existing maintenance management framework gaps And developed maintenance management framework fit for case company
Mahilet Mentesinot 2017	Enhancing productivity through improved maintenance system	To improve the productivity by identifying the maintenance problems and increasing the machine productivity to get higher profit	Survey and questionnaire	Machine down time is one of the main problems for maintenance in the company Identify bottleneck machines and critical components
Meseret 2007	Productivity improvement through maintenance management in Ethiopian textile industries	Identify maintenance problem and its causes and suggest maintenance management system that increases productivity.	Interviews, Survey and questionnaire TPM	Identify the bottleneck machines, downtime and its cost Finds out the causes of breakdown and ways to minimize them in order to increase the machines availability

Misikir Teklemariam 2004	Productivity improvement in Ethiopian leather industry through efficient maintenance management		TPM	Identifying bottleneck machine, factor retarding productivity, analyses down time cost and based on the result propose maintenance work flow